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(51) International Patent Classification ⁶ : A61K 39/12, 39/205, 39/235, C12N 7/01, 15/00, 15/09	A1	(11) International Publication Number: WO 96/39178 (43) International Publication Date: 12 December 1996 (12.12.96)
(21) International Application Number: PCT/US96/09495 (22) International Filing Date: 5 June 1996 (05.06.96) (30) Priority Data: 08/461,837 5 June 1995 (05.06.95) US 60/000,078 8 June 1995 (08.06.95) US (60) Parent Applications or Grants (63) Related by Continuation US 08/461,837 (CIP) Filed on 5 June 1995 (05.06.95) US 60/000,078 (CIP) Filed on 8 June 1995 (08.06.95) (71) Applicants (for all designated States except US): THE WISTAR INSTITUTE OF ANATOMY AND BIOLOGY [US/US]; 36th & Spruce Streets, Philadelphia, PA 19104-4268 (US). TRUSTEES OF THE UNIVERSITY OF PENNSYLVANIA [US/US]; 133 South 36th Street, Philadelphia, PA 19104-3246 (US). (72) Inventors; and (75) Inventors/Applicants (for US only): ERTL, Hildegund, C., J. [DE/US]; 1929 West Montgomery Avenue, Villanova,	PA 19085 (US). WILSON, James, M. [US/US]; 1350 N. Avignon Drive, Gladwyne, PA 19035 (US). (74) Agents: BAK, Mary, E. et al.; Howson and Howson, Spring House Corporate Center, P.O. Box 457, Spring House, PA 19477 (US). (81) Designated States: AU, CA, JP, US, European patent (AT, BE, CH, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE). Published <i>With international search report.</i> <i>Before the expiration of the time limit for amending the claims and to be republished in the event of the receipt of amendments.</i>	
(54) Title: A REPLICATION-DEFECTIVE ADENOVIRUS HUMAN TYPE 5 RECOMBINANT AS A VACCINE CARRIER		
(57) Abstract <p>A replication defective recombinant adenovirus is provided which contains a complete deletion of its E1 gene and at least a partial deletion of its E3 gene, said virus containing in the site of the E1 deletion a sequence comprising a non-adenovirus promoter directing the replication and expression of DNA encoding a heterologous protein from a disease-causing agent, which, when administered to a mammal in said recombinant virus, elicits a substantially complete protective immune response against the agent. Pharmaceutical and veterinary products containing the recombinant adenovirus are provided.</p>		

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A REPLICATION-DEFECTIVE ADENOVIRUS HUMAN TYPE 5
RECOMBINANT AS A VACCINE CARRIER

This invention was supported by the National
Institutes of Health Grant Nos. NIH AI 33683-02 and NIH
5 AI 27435-05. The United States government has certain
rights in this invention.

Field of the Invention

This invention relates generally to recombinant
adenoviruses as vaccine components, and more
10 particularly, to the use of replication deficient
adenoviruses as vaccine carriers, which induce protective
immune responses in mammalian hosts.

Background of the Invention

A replication competent, recombinant adenovirus
15 (Ad) is an adenovirus with intact or functional essential
genes, (i.e., E1a, E1b, E2a, E2b and E4). Such
recombinant viruses containing a variety of inserted
genes have been used as vaccine compositions with some
success [see, e.g. Davis, U.S. Patent No. 4,920,309].

20 One of these recombinant adenoviruses
expressing the rabies G protein was shown to induce
protective immunity in animals upon challenge with rabies
virus [L. Prevac, J. Infect. Dis., 161:27-30 (1990)].
However, doses above 10^6 plaque-forming units (pfu) of
25 this replication-competent virus were required to induce
complete protection to viral challenge. Further, the use
of these viruses in a live form capable of replicating in
vivo is an undesirable attribute of a vaccine component.

In contrast, adenoviruses which have been made
30 replication deficient by deletion of the Ad E1a and E1b
genes have been used primarily for gene therapy protocols
[See, e.g., Kozarsky and Wilson, Curr. Opin. Genet. Dev.,
3:499-503 (1993); Kozarsky et al, Som. Cell Mol. Genet.,
19:449-458 (1993); see also, International Patent

Application No. WO95/00655, published Jan. 5, 1995].

Such recombinant, replication deficient adenoviruses have been found to induce cell-mediated immune responses [Y. Yang et al, Proc. Natl. Acad. Sci. USA, 91:4407 (1994) and Y. Yang et al, Immunity, 1:433-442 (August 1994)] and neutralizing antibodies [T. Smith et al, Gene Therapy, 5:397 (1993); K. Kozarsky et al, J. Biol. Chem., 269:13695 (1994)]. None of these articles relating to the use of recombinant replication deficient Ad in gene therapy have measured the induction of a protective immune response.

Others have described the insertion of a foreign gene into a replication-defective adenovirus for putative use as a vaccine [See, e.g. T. Ragot et al, J. Gen. Virol., 74:501-507 (1993); M. Eliot et al, J. Gen. Virol., 71:2425-2431 (1990); and S. C. Jacobs et al, J. Virol., 66:2086-2095 (1992)]. Jacobs et al, cited above, describes a recombinant E1-deleted, E3 intact, Ad containing encephalitis virus protein NS1 under the control of a heterologous cytomegalovirus (CMV) promoter. When mice were immunized with the recombinant Ad vaccines and challenged with virus, Jacobs et al obtained only partial protection (at most a 75% protection) for an average survival of 15 days. Eliot et al, cited above, describe a recombinant E1-deleted, partially E3-deleted Ad with pseudorabies glycoprotein 50 inserted into the E1 deletion site under the control of a homologous Ad promoter. In rabbits and mice, after immunization and challenge, only partial protection was obtained (i.e., about one-third). Ragot et al, cited above, describe a recombinant E1-deleted, partially E3-deleted Ad with Epstein Barr virus glycoprotein gp340/220 inserted into the E1 deletion site under the control of a homologous Ad promoter. In marmosets (tamarins) after three high dose (5 x 10⁹ pfu, 1 x 10¹⁰ pfu and 2 x 10¹⁰ pfu), intramuscular

immunizations and viral challenge, full protection was obtained.

For certain highly infectious diseases, such as rabies, there is a demand for an effective vaccine.

5 Desirably, a vaccine should be effective at a low dosage to control the occurrence of side effects or to enable sufficient amounts of vaccine to be introduced into animals in the wild. Currently, a vaccinia rabies glycoprotein (VRG) vaccine is being used for oral wild-
10 life immunization [B. Brochier et al, Vaccine, 12:1368-1371 (1994)]. However, doses above 10^6 pfu are required to induce complete protection.

There thus remains a need in the art for a method of vaccinating against various disease states, and
15 particularly rabies, which is safe and highly effective.

Summary of the Invention

The inventors have surprisingly found compositions and methods of vaccinating a human and/or animal against a disease using an adenovirus defective
20 vaccine composition, which produces a high level of protection upon administration of a low vaccine dose. For example, vaccination with a vaccine composition described herein, which is directed against rabies, has been found to require as little as a single dose of 10^4
25 pfu of rabies vaccine vector to induce complete protection. This effect is also accomplished by administration routes other than the oral route.

Thus, in one aspect, the invention provides a replication-defective recombinant adenovirus (rAd)
30 vaccine containing DNA encoding a selected heterologous protein from a disease-causing agent, which elicits a protective immune response against the agent. This recombinant adenovirus of the invention contains at least a partial, but functional, deletion of the Ad E3 gene.

Further in the site of the Ela/E1b deletion which renders the Ad replication-defective, the recombinant virus contains a sequence comprising a non-adenovirus promoter directing the replication and expression of the DNA encoding the heterologous protein. For example, an
5 exemplary rAd is Adrab.gp, which contains a rabies gp gene and is useful in a method for treating or preventing rabies.

In another aspect, the invention provides
10 pharmaceutical and veterinary compositions which contain the rAd of the invention.

In still another aspect, the invention provides for the use of the rAd in the manufacture of the compositions described above.

15 In yet a further aspect, the invention provides a method of vaccinating a human or animal against disease comprising administering to said human or animal an effective amount of a replication-defective recombinant adenovirus vaccine containing DNA encoding a selected
20 heterologous protein which elicits a protective immune response against an agent causing the disease. This adenovirus of the invention contains at least a partial, but functional, deletion of the Ad E3 gene. Further in the site of the Ela/E1b deletion which renders the Ad
25 replication-defective, the recombinant virus contains a sequence comprising a non-adenovirus promoter directing the replication and expression of the DNA encoding the heterologous protein.

In another aspect, the present invention
30 provides a method of preventing rabies infection in an animal comprising administering to the animal an effective amount of a recombinant replication-defective Adrab.gp adenovirus containing DNA encoding a rabies virus glycoprotein.

Other aspects and advantages of the present invention are described further in the following detailed description of the preferred embodiments thereof.

Brief Description of the Drawings

5 Fig. 1A is a schematic representation of the 1650 bp rabies glycoprotein gene from Evelyn Rockitniki Abelseth strain excised from the pSG5.ragp plasmid by cleavage with BglIII. The 1650 bp sequence spans nucleotide 1178 to 2827 of SEQ ID NO: 1.

10 Fig. 1B is a schematic map of the pAd.CMVlacZ (also known as H5.020CMVlacZ) plasmid, which contains adenovirus map units (m.u.) 0-1 as represented by the black bar at the top of the circular plasmid, followed by a cytomegalovirus enhancer/promoter (CMV enh/prom) represented by the striped arrow to the right of the
15 black bar, a human betagalactosidase gene represented by the dark gray bar at the righthand side of the circular plasmid; a polyadenylation signal represented by the short white bar at the bottom of the circular plasmid,
20 adenovirus m.u. 9-16 represented by the long black bar at the lower lefthand portion of the circular plasmid and plasmid sequences from plasmid pAT153 including an origin of replication and ampicillin resistance gene represented by the light gray bar at the upper lefthand portion of
25 the circular plasmid. Restriction endonuclease enzymes are represented by conventional designations in this plasmid. NotI digestion removes the LacZ gene from this plasmid.

 Fig. 1C is a schematic map of the plasmid
30 pAdCMV.rabgp which results from blunt end cloning of the BglIII fragment of pSG5.ragp to the larger NotI fragment of pAdCMV.lacZ. pAdCMV.ragpp is substantially similar to the pAd.CMVlacZ plasmid, but which contains the rabies glycoprotein sequence in place of the lacZ gene.

pAdCMV.rabgp [SEQ ID NO: 1] contains adenovirus m.u. 0-1 as represented by the black bar at the top of the circular plasmid (nucleotides 12 to 364 of SEQ ID NO: 1); followed by a cytomegalovirus enhancer/promoter (CMV enh/prom) represented by the striped arrow to the right of the black bar [nucleotides 382 to 863 of SEQ ID NO: 1]; a rabies glycoprotein gene represented by the dotted bar at the righthand side of the circular plasmid (nucleotides 1178 to 2827 of SEQ ID NO: 1); a polyadenylation signal represented by the short white bar at the lower righthand portion of the circular plasmid [nucleotides 2836-3034 of SEQ ID NO: 1]; adenovirus m.u. 9-16 represented by the long black bar at the lower portion of the circular plasmid (nucleotides 3061 to 5524 of SEQ ID NO: 1); and plasmid sequences from plasmid pAT153 including an origin of replication and ampicillin resistance gene represented by the light gray bar at the upper lefthand portion of the circular plasmid (nucleotides 5525 to 8236 of SEQ ID NO: 1). Restriction endonuclease enzymes are represented by conventional designations. SEQ ID NO: 2 provides the rabies protein sequence encoded by the nucleotide sequence within pAdCMV.rabgp.

Fig. 1D is a schematic map of recombinant adenovirus Adrab.gp (also known as H5.020CMV.rab), which results from homologous recombination between pAdCMV.rabgp and Ad strain dl7001. Ad dl7001 is an Ad5 variant that carries an approximately 3 kb deletion of the Ad5 sequence (GenBank Accession No. M73260) between m.u. 78.4 through 86. The CMV/rabies glycoprotein/pA minicassette of pAd.CMVrab is inserted between deleted adenovirus m.u.1 and 9, with the remaining Ad5 m.u. 9-100 having the above-mentioned E3 gene deletion. Restriction endonuclease enzymes are represented by conventional designations.

Fig. 2 is a bar graph plotting ^3H -thymidine ([^3H]TdR) incorporation, measured at counts per minute \pm standard deviation (cpm \pm SD), for irradiated splenocytes plated at 5×10^5 cells per well of a round bottom microtiter plate and incubated with 5 (diagonally striped), 1 (cross-hatched) or 0.2 (solid) $\mu\text{g/ml}$ of betapropionolactone-inactivated Evelyn Rockitniki Abelseth rabies strain (ERA-BPL) or approximately 1 (diagonally striped), 0.1 (cross-hatched), and 0.01 (solid) pfu of Adrab.gp per cell or medium only as a negative control for 60 minutes at 37°C . As described in Example 2B, after cloned T cells were added, cells were pulsed two days later for 6 hours with ^3H -thymidine, harvested and counted in a β -counter.

Fig. 3A is a graph plotting % specific lysis (means of triplicates \pm SD) vs. effector:target cell ratio for groups of C3H/He mice inoculated with 2×10^6 pfu of Adrab.gp (solid box) or H5.020CMVlacZ (open box), as described in Example 4B. Splenocytes were harvested 14 days later and co-cultured for 5 days with 1 pfu of Adrab.gp virus per cells. Activated lymphocytes were then tested at different E:T ratios on H-2 compatible L929 cells stably transfected with a rabies virus G protein-expressing vector (t.L929rab.gp) in a 4 hour ^{51}Cr -release assay.

Fig. 3B is a graph of an experiment similar to Fig. 3A, but in which the activated lymphocytes were tested at different E:T ratios on H-2 compatible L929 cells stably transfected with a neomycin-expressing vector (t.L929.neo) in the ^{51}Cr -release assay, as a control.

Fig. 4A is a graph plotting number of cells vs. intensity of fluorescence for L929 fibroblasts plated in 24-well Costar plates in medium supplemented with 2% fetal bovine serum (FBS) following infection with 1

pfu/cell of VRG, as described in Example 5 below. Cells harvested 12 hours after infection and stained by indirect immunofluorescence with monoclonal antibody (MAb) 509-6 were analyzed by fluorescence activated cell sorting (FACS). The line on the graph labeled "B" is the threshold below which 99% of the population are negative. Line "C" represents the region that encompasses all events on the histogram.

Fig. 4B is a graph similar to Fig. 4A above, except the cells were harvested 36 hours after infection.

Fig. 4C is a graph similar to Fig. 4A above, except the cells were harvested 60 hours after infection.

Fig. 4D is a graph similar to Fig. 4A above, except the cells, harvested 12 hours after infection, were stained using cells treated only with the fluorescein isothiocyanate (FITC)-labeled goat anti-mouse immunoglobulin (Ig) as a control.

Fig. 4E is a graph similar to Fig. 4D above, except the cells were harvested 36 hours after infection.

Fig. 4F is a graph similar to Fig. 4D above, except the cells were harvested 60 hours after infection.

Fig. 4G is a graph similar to Fig. 4A above, except the cells were infected with 1 pfu Adrab.gp virus, and cells were harvested 12 hours after infection.

Fig. 4H is a graph similar to Fig. 4G, except the cells were harvested 36 hours after infection.

Fig. 4I is a graph similar to Fig. 4G, except the cells were harvested 60 hours after infection.

Fig. 4J is a graph similar to Fig. 4G above, except the cells were stained by indirect immunofluorescence using cells treated only with FITC-labeled goat anti-mouse Ig as a control.

Fig. 4K is a graph similar to Fig. 4J above, except the cells were harvested 36 hours after infection.

Fig. 4L is a graph similar to Fig. 4J above, except the cells were harvested 60 hours after infection.

Fig. 5A is a graph plotting optical density at 405 nm vs. serum dilution for duplicate samples \pm SD, as described in Example 6B below for mice immunized with a replication-competent E3 deleted adenovirus (open box) or Adrab.gp (solid box). Native age-matched control mice were used as controls (X). Mice were bled 10 days after immunization and serum antibody titers to adenoviral antigens were determined by an ELISA on plates coated with 1 μ g/mL of purified H5.020CMVlacZ virus.

Fig. 5B is a graph similar to that of Fig. 5A for mice immunized as described in Fig. 6A below, and bled at 16 days.

Fig. 6A is a graph plotting mean percentage (%) specific lysis of triplicates \pm SD vs. E:T cell ratio for C3H/He mice inoculated with 10^6 pfu of replication competent E3 deleted adenovirus and boosted 3 weeks later with Adrab.gp (open box). Control mice were inoculated with Adrab.gp only (solid box). Mice were sacrificed 4 weeks later and upon restimulation with 1 pfu of Adrab.gp per cell tested on a 4 hour ^{51}Cr -release assay on L929 cells stably transfected with pSG5rab.gp. See Example 6.

Fig. 6B is a graph similar to Fig. 6A, except the L929 cells were transfected with pSV2neo.

Fig. 7 is a graph plotting % survival of vaccinated mice vs. days after challenge with rabies virus. Mice were challenged 3 days (open triangle), 7 days (open square), and 10 days (solid square) after vaccination. X represents naive mice controls. See, Example 7.

Detailed Description of the Invention

The present invention provides compositions and methods of effectively inducing a protective immune

response to a disease agent. The compositions include a recombinant replication-defective adenovirus, and pharmaceutical and veterinary compositions containing the rAd. The rAd backbone was previously used for gene therapy. As discussed herein, the inventors have surprisingly found that use of such a recombinant Ad, described in detail below, provides substantially complete immune protection in vaccinates.

By "substantially complete" protection is meant when administered in an effective amount, the recombinant adenovirus presents an immunogenic protein in such a manner that a protective immune response is observed in substantially all vaccinates after a single administration. By "substantially all" is meant greater than 90% of the vaccinates. Unexpectedly, the recombinant vaccine permits successful vaccination with very few booster administrations. Also unexpectedly, the recombinant vaccine permits vaccination at an unexpectedly lower dosage than is normally used in similar vaccines in which the same protein is present in another recombinant virus. For example, immunization of mice with a single dose of as little as 10^4 pfu of the recombinant, replication defective Ad containing a rabies glycoprotein has been observed to induce complete protection against rabies infection. Partial protection was seen seven days after immunization.

While not wishing to be bound by theory, the inventors currently believe that this recombinant, replication defective Ad vaccine is advantageous over, e.g., the vaccinia vaccine, because it permits lower doses of antigen to be expressed for an extended period of time by a non-lytic virus. For example, although vaccinia expresses higher doses of antigen, e.g., a rabies antigen, it is a lytic virus which causes a rapid demise of infected cells. The finding that the

recombinant replication-defective Ad, e.g., Adrab.gp virus, used in the method of the present invention is more efficacious than the currently used vaccinia rabies (VRG) vaccine is unexpected and incompatible with current thinking that the antigenic dose governs the magnitude of the immune response. The use of the recombinant replication defective adenovirus also confers safety and efficacy advantages over other vaccine carriers, such as vaccinia. The adenovirus construct results in slow accumulation of the rabies virus G protein on the surface of infected cells without causing visible cell damage (data not shown). In contrast, cells infected with VRG recombinant rapidly express substantial amounts of the rabies virus G protein on the cell surface but then die shortly after infection. The adenoviral construct persists for at least seven days in immunocompetent mice.

With respect to safety, the present invention provides a recombinant replication-defective Ad which is thus highly unlikely to spread within a host or among individuals, particularly in view of the fact that the recombinant, E1-deleted dl7001 Ad virus, which is the backbone of the exemplary replication defective recombinant Ad used in the examples below has already been approved for use in humans for gene therapy, i.e., for the replacement of faulty or missing genes. The recombinant virus lacks oncogenic potential because the E1 gene that can function as an oncogene in some adenovirus strains has been deleted. Further, cells infected with the recombinant, replication defective adenovirus are completely eliminated by CD8 T cells within 21 days in immunocompetent hosts.

With respect to efficacy, the recombinant, replication defective Ad of this invention is highly efficacious at inducing cytolytic T cells and antibodies to the inserted heterologous protein expressed by the

virus. This has been demonstrated with a recombinant, replication defective Ad containing a sequence encoding the rabies virus glycoprotein as the heterologous gene, which Ad has been administered to animals by other than the oral route.

The recombinant virus of this invention is also surprisingly more effective as a vaccine than other, previously reported, replication defective adenovirus vaccines. See, for example, Ragot et al, Eliot et al, and Jacobs et al, all cited above. In contrast to the other replication defective adenovirus vaccines, the vaccine composition useful in the present invention can be used at lower doses. This vaccine can also be administered in a single inoculation to obtain substantially complete protection.

For these reasons, the recombinant replication-defective adenovirus of the invention and particularly the preferred embodiment which makes use of the pAdCMV.lacZ (or H5.020CMVlacZ) Ad vector described below, can be used as a prophylactic or therapeutic vaccine against any pathogen for which the antigen(s) crucial for induction of an immune response able to limit the spread of the pathogen has been identified and for which the cDNA is available.

I. The Recombinant Adenovirus

As used herein, the term "minicassette" refers to the nucleotide sequence comprised of (a) a non-Ad promoter, which directs the replication and expression of (b) the following nucleotide sequence which encodes a heterologous protein immunogen, which is followed by (c) a polyA nucleotide sequence. By "vector or plasmid" is meant the construct comprised of 5' sequences of the Ad virus (usually Ad m.u. 0-1) deleted of the E1 gene (which occurs between Ad m.u. 1-9), which may contain a heterologous nucleotide sequence, but which does not

contain the 3' end of the Ad virus (generally between about Ad m.u. 16 to 100), but rather conventional plasmid sequences. This vector does not contain all of the genes essential to a replicative virus. By "recombinant, replication defective Ad" is meant the infectious recombinant virus, deleted of its E1 gene, into which location is inserted the minicassette, and which contains all of the 3' sequences essential to an infectious virus except for a functional deletion in the E3 gene region.

The recombinant virus of the method of the invention is a replication-defective recombinant adenovirus containing a deletion of its E1 gene and at least a partial, functional deletion of its E3 gene. In the site of the E1 deletion a minicassette is inserted, which comprises a nucleotide sequence encoding a heterologous protein immunogen and a non-adenovirus promoter directing the replication and expression of the nucleotide sequence encoding the heterologous protein.

Any Ad that infects the target cells is appropriate for use in this invention. Desirable adenoviruses are human type C adenoviruses, including serotypes Ad2 and Ad5. The DNA sequences of a number of adenovirus types, including type Ad5, are available from GenBank [Accession No. M73260]. The adenovirus sequences may be obtained from any known adenovirus type, including the presently identified 41 human types [Horwitz et al, Virology, 2d ed., B. N. Fields, Raven Press, Ltd., New York (1990)]. Similarly, adenoviruses known to infect other animals may also be employed in this invention. The selection of the adenovirus type and strain is not anticipated to limit the following invention. A variety of adenovirus strains are available from the American Type Culture Collection, Rockville, Maryland, or available by request from a variety of commercial and institutional sources. In the following exemplary

embodiment, an adenovirus type 5 (Ad5) sequence obtained from GenBank [Acc. No. M73260] is used for convenience.

Adenoviruses of the present invention are replication defective, i.e., intact adenoviruses which
5 have been rendered replication defective by deleting the early gene locus that encodes E1a and E1b. See, K.F. Kozarsky and J. M. Wilson, Curr. Opin. Genet. Dev., 3:499-503 (1993). Similarly, a replication defective adenovirus may be designed by deleting less than the
10 entire E1a and E1b locus, but enough to functionally disable the E1 genes.

An additional characteristic of the Ad useful in this invention is that the E3 gene is deleted, i.e., from about m.u. 78.5 to about m.u. 84.3 of Ad5. While
15 the presently preferred embodiment contains a complete deletion of that sequence, it may be possible to partially delete the E3 sequence to disable the functional abilities of the E3 gene.

A preferred recombinant Ad virus may be
20 produced by using a plasmid vector pAd.CMVlacZ as described in Fig. 1B. This plasmid contains adenovirus sequences Ad m.u. 0-1 (i.e., it is fully deleted of E1a and E1b genes), after which a selected minigene may be inserted, e.g., the rabies glycoprotein under control of
25 a heterologous promoter and other regulatory sequences, if desired, followed by the sequence Ad m.u.9 to 16 and plasmid sequences. When this vector is manipulated to place a minicassette into the E1 deletion site, and supplied with the remaining 3' Ad sequences with a full
30 deletion of E3 and cultured in a helper cell line, the resulting recombinant adenovirus is capable of functioning as a rabies vaccine. This recombinant virus, called Adrab.gp or H5020.CMVrab, is described in detail in Example 1 and in flow chart form in Figs. 1A through
35 1D.

The preferred recombinant Ad of this invention contains a minicassette which uses the cytomegalovirus (CMV) promoter [see, e.g., Boshart et al, Cell, 41:521-530 (1985)] to control the expression of the inserted
5 heterologous gene. The promoter is inserted in the site of the E1 deletion and directs the replication and expression of the protein encoded by the selected heterologous gene. However, this invention is not limited by the selection of the promoter, except that the
10 promoter should be heterologous to the Ad virus, i.e., the E1 Ad promoter is replaced using techniques known to those of skill in the art. Other desirable promoters include the Rous sarcoma virus LTR promoter/enhancer, the SV40 promoter, and the chicken cytoplasmic β -actin
15 promoter [T. A. Kost et al, Nucl. Acids Res., 11(23):8287 (1983)]. Still other promoter/enhancer sequences may be readily selected by one of skill in the art.

As discussed above, in the site of the E1 deletion, and under control of a promoter heterologous to
20 Ad, a nucleic acid sequence, preferably in the form of DNA, encoding a protein heterologous to the Ad is inserted using techniques known to those of skill in the art.

The heterologous nucleic acid encodes a protein
25 which is desirably capable of inducing an immune response to a pathogen. Such a protein may be a protein from rabies virus, human papilloma virus, human immunodeficiency virus (HIV), respiratory syncytial virus (RSV). The vaccine method of the present invention may
30 also be employed with a tumor-associated protein specific for a selected malignancy. These tumor antigens include viral oncogenes, such as E6 and E7 of human papilloma virus or cellular oncogenes such as mutated ras or p53. Particularly, where the condition is human
35 immunodeficiency virus (HIV) infection, the protein is

preferably HIV glycoprotein 120 for which sequences are available from GenBank. Where the condition is human papilloma virus infection, the protein is selected from the group consisting of E6, E7 and/or L1 [Seedorf, K. et al, Virology, 145:181-185 (1985)]. Where the condition is respiratory syncytial virus infection, the protein is selected from the group consisting of the glyco- (G) protein and the fusion (F) protein, for which sequences are available from GenBank. In addition to these proteins, other virus-associated proteins are readily available to those of skill in the art. Selection of the heterologous proteins is not a limiting factor in this invention.

In a particularly preferred embodiment, the condition is rabies and the protein is the rabies glycoprotein [see, U.S. Patent No. 4,393,201]. A variety of rabies strains are well known and available from academic and commercial sources, including depositaries such as the American Type Culture Collection, or may be isolated using known techniques. The strain used in the examples below is the Evelyn Rockitniki Abelseth (ERA) strain. However, this invention is not limited by the selection of the rabies strain.

In a preferred embodiment, cDNA encoding the rabies virus glycoprotein is inserted under control of a CMV promoter into the pAdCMV.lacZ (or H5.020CMVlacZ) Ad vector and supplied with the essential genes for infectivity and viral formation in a helper cell line using standard techniques, as described in detail in Example 1. Immunization studies revealed that a single administration of the resulting recombinant replication defective virus conferred complete protection at a relatively low dose following challenge with rabies virus.

II. Formulation of Vaccine

A recombinant replication defective Ad bearing a gene encoding an immunogenic protein may be administered to a human or veterinary patient, preferably
5 suspended in a biologically compatible solution or pharmaceutically acceptable delivery vehicle. A suitable vehicle is sterile saline. Other aqueous and non-aqueous isotonic sterile injection solutions and aqueous and non-aqueous sterile suspensions known to be pharmaceutically
10 acceptable carriers and well known to those of skill in the art may be employed for this purpose.

Optionally, a vaccinal composition of the invention may be formulated to contain other components, including, e.g. adjuvants, stabilizers, pH adjusters,
15 preservatives and the like. Such components are well known to those of skill in the vaccine art.

III. Administration of Vaccine

The recombinant, replication defective viruses are administered in an "effective amount", that is, an
20 amount of recombinant virus that is effective in a route of administration to transfect the desired cells and provide sufficient levels of expression of the selected gene to provide a vaccinal benefit, i.e., protective immunity.

25 Conventional and pharmaceutically acceptable routes of administration include intranasal, intramuscular, intratracheal, subcutaneous, intradermal, rectal, oral and other parental routes of administration. Routes of administration may be combined, if desired, or
30 adjusted depending upon the immunogen or the disease. For example, in prophylaxis of rabies, the subcutaneous, intratracheal and intranasal routes are preferred. The route of administration primarily will depend on the nature of the disease being treated.

Doses or effective amounts of the recombinant replication defective Ad virus will depend primarily on factors such as the condition, the selected gene, the age, weight and health of the animal, and may thus vary among animals. For example, a prophylactically effective amount or dose of the Ad vaccine is generally in the range of from about 100 μ l to about 10 ml of saline solution containing concentrations of from about 1×10^4 to 1×10^7 plaque forming units (pfu) virus/ml. A preferred dose is from about 1 to about 10 ml saline solution at the above concentrations. The levels of immunity of the selected gene can be monitored to determine the need, if any, for boosters.

Currently, when vaccinating against rabies, the preferred dose is about 10^4 pfu of the recombinant virus per mouse, preferably suspended in about 0.1 mL saline. Thus, when vaccinating against rabies infection, a larger animal would preferably be administered about a 1 mL dose containing about 1×10^5 Adrab.gp pfu suspended in saline. Following an assessment of antibody titers in the serum, optional booster immunizations may be desired.

The following examples illustrate the preferred methods for preparing the vectors and the recombinant viruses used in the vaccine and method of the invention. These examples are illustrative only and do not limit the scope of the invention.

Example 1 - Production and Purification of Vectors and Viruses

A. Adrab.gp

A recombinant, replication defective adenovirus expressing the rabies virus G protein of the Evelyn Rockitniki Abelseth (ERA) strain of rabies virus [ATCC VR-332; U. S. Patent No. 3,423,505] (ERA) was

constructed as follows. See the flowchart of Figs. 1A to 1D.

The 1650 bp rabies virus G cDNA (nucleotides 1178 to 2827 of SEQ ID NO: 1) was purified from the pSG5rab.gp plasmid [S.R. Burger et al, J. Gen. Virol., 72:359-367 (1991)] upon digestion with BglIII, and blunt-ended with Klenow to supply the G gene. See also United States Patent No. 4,393,201, issued July 12, 1983.

The pAd.CMVlacZ vector [J. Wilson et al, Hum. Gene Ther., 5:501-519 (1994); K. Kozarsky et al, J. Biol. Chem., 269:13695-13702 (1994)], which contains Ad5 m.u. 0-1, followed by the cytomegalovirus (CMV) enhancer/promoter, the beta galactosidase (lacZ) gene, a polyadenylation signal (pA), adenovirus m.u. 9-16 and plasmid sequences from plasmid pAT153 including an origin of replication and ampicillin resistance gene, was completely digested with NotI to remove the lacZ gene and provide an ~5.6 kb backbone.

The cDNA encoding the rabies G protein, described above, was inserted into this 5.6 kb fragment via blunt-end cloning to generate pAdCMV.rabgp, which is similar to pAd.CMVlacZ but contains the rabies sequence in place of the lacZ gene. The appropriate orientation of the insert was confirmed by restriction enzyme mapping. pAdCMV.rabgp [SEQ ID NO: 1] contains adenovirus m.u. 0-1 (nucleotides 12 to 364 of SEQ ID NO: 1); followed by a cytomegalovirus enhancer/promoter (nucleotides 382 to 863 of SEQ ID NO: 1); the rabies glycoprotein gene (nucleotides 1178 to 2827 of SEQ ID NO: 1); a polyadenylation signal (nucleotides 2836-3034 of SEQ ID NO: 1); adenovirus m.u. 9-16 (nucleotides 3061 to 5524 of SEQ ID NO: 1); and plasmid sequences from plasmid pAT153 (nucleotides 5525 to 8236 of SEQ ID NO: 1). The remaining nucleotides of SEQ ID NO: 1 are the result of cloning and plasmid construction.

To provide a recombinant virus capable of infecting a cell, the 3' end of the adenovirus sequence was needed to replace the pAT153 plasmid sequences of pAdCMV.rabgp. The plasmid pAdCMV.rabgp was linearized with NheI. The linearized plasmid was co-transfected into 293 packaging cells [ATCC CRL 1573] which contain and express the transforming genes of human adenovirus type 5 to allow replication of the adenovirus [F. L. Graham et al, J. Gen. Virol., 36:59-72 (1977)]. The transfected packaging cells were grown in DMEM with 10% FBS without HEPES buffer in a 5% CO₂ incubator with an E3 deleted Ad5 DNA [Ad5dl7001, a variant that carries a 3 kb deletion between m.u. 78.4 through 86 in the nonessential E3 region (provided by Dr. William Wold, Washington, University, St. Louis, MO)]. This Ad5dl7001 had been digested with a restriction enzyme ClaI to remove the left end, i.e., 917 bp from the 5' end of the adenovirus sequence, rendering the DNA non-infectious.

Following the co-transfection, only products of homologous recombination which occurred between Ad m.u. 9-16 of the pAdCMV.rabgp and the 5' deleted-Ad5dl7001 could produce replicative Ad virus in 293 cells. That is, when homologous recombination occurred, the 3' end of pAd.rabgp from about Ad m.u. 9 to about m.u. 16 and all of the plasmid sequence was swapped with the 3' end of the 5' truncated Ad5dl7001 virus, from about Ad m.u. 9 through m.u. 100.

Several recombinant viral plaques were harvested and tested for expression of the rabies virus G protein as described below. One recombinant, replication defective clone termed Adrab.gp was purified by two rounds of plaque purification and used for further studies and is illustrated schematically in Fig. 1D above.

The recombinant, replication defective Ad Adrab.gp contains Ad5 m.u. 0-1, followed by the CMV enhancer/promoter, the rabies G gene, a pA site, and Ad5 m.u. 9-78.4 and 86-100.

5 B. H5.010CMVlacZ

The recombinant replication defective Ad, H5.010CMVlacZ, is substantially identical to Adrab.gp, except that this virus contains *E. coli* lacZ in place of the rabies G protein and only a partial deletion of E3.

10 The plasmid pAd.CMVlacZ described above, was linearized with NheI and co-transfected into 293 cells with a partially E3 deleted Ad5 DNA (sub 360 DNA, H5sub360), which had been digested with ClaI to eliminate the sequence of m.u. 83.5 to 85. As above, homologous
15 recombination, followed by plating and harvesting produced the resulting recombinant adenovirus, designated H5.010CMVlacZ. This virus contains the sequence from Ad5 m.u. 0-1, followed by the CMV enhancer/promoter, the *Escherichia coli* lacZ gene, a pA site, and Ad5 m.u. 9-
20 83.5 and 85-100.

 C. Viral Propagation and Purification

The adenoviral recombinants, Adrab.gp H5.010CMVlacZ, and Ad5dl7001, a replication competent adenovirus, on 293 cells for 72 hours. Virus was
25 recovered on the third round of freeze-thawing. Cell-free supernatants were either used directly or they were further purified by CsCl density centrifugation. Viral stocks were titrated on 293 cells using a plaque assay.

Example 2 - Immunofluorescence and T Cell Studies

30 To confirm that the Adrab.gp recombinant virus expresses the rabies virus G protein on infected cells in a form recognized by antibodies and cytolytic T cells directed against rabies virus, a series of *in vitro* experiments were performed initially.

A. Indirect Immunofluorescence

To assess the conformation of the G protein as expressed by the Adrab.gp virus, HeLa cells [which had been maintained in Dulbecco's minimal essential medium (DMEM) supplemented with 10% FBS, HEPES buffer and antibiotics in a 10% CO₂ incubator] were infected for 48 hours with 1 pfu of Adrab.gp virus per cell or as a control with H5.020CMVlacZ. Cells were stained 24 hours later by an indirect immunofluorescence assay using three MABs (designated 523-11, 509-6, and 1112-1, and prepared using a 1:100 to 1:1000 dilution of ascitic fluid) to different conformation-dependent binding sites of the rabies virus G protein. The B cell hybridoma cells 509-6, 1112-1, and 523-11 secrete antibodies to different antigenic sites of the rabies virus G protein (509-6 to site I, 1112-1 to site II, and 523-11 to site III [T.J. Wiktor et al, Proc. Natl. Acad. Sci. USA, 75:3938-3945 (1978)]). These hybridoma cells were grown in DMEM supplemented with 10% FBS. Ascetic fluid was prepared in BALB/c mice. The assay was performed as follows.

The HeLa cells were infected for various times with 1 pfu of recombinant adenovirus or with 1 pfu of the vaccinia VRG virus described above per cell in 24-well Costar plates seeded with 5×10^5 cells per well. Cells were harvested at varied times after infection by treatment with trypsin and incubated for 60 minutes on ice with the MABs identified above. Cells were washed once with phosphate-buffered saline (PBS) and then incubated with a FITC-labeled goat anti-mouse immunoglobulin (Ig) antibody. Cells were washed and analyzed by a fluorescence activated cell sorter (FACS). Alternatively cells adherent to glass cover slips were stained with the same antibody preparations for subsequent analysis with confocal microscopy.

For all of the antibodies, Adrab.gp virus-infected cells exhibited surface staining with the antibody, while cells infected with the control recombinant virus expressing lacZ were negative.

5

B. T Cell Proliferation Assay

Further *in vitro* studies showed that the recombinant virus Adrab.gp induced proliferation of a rabies virus G protein specific T helper cell clone in the presence of syngeneic, γ -irradiated splenocytes (Fig. 2). In a separate experiment, this T cell clone did not proliferate in the presence of H5.010CMVlacZ (data not shown).

10

A rabies virus-specific helper T cell clone, obtained from splenocytes of VRG immune C3H/He mice in the inventors' laboratory, was cultured (2×10^4 cells/well) in 96-well round-bottom microtiter plate with 5×10^5 irradiated syngeneic C3H/He splenocytes pretreated with different antigen preparations (1, 0.1 and 0.01 pfu Adrab.gp per cell) in DMEM supplemented with 2% FBS and 10^{-6} M 2-mercaptoethanol and 10% rat Concanavalin A supernatant as a lymphokine source as described previously [L. Otvos, Jr., Biochim. Biophys. Acta, 1224:68-76 (1994)]. Proliferation of the cloned T cells was assessed 48 hours later by a 6 hour pulse with 0.5 μ Ci of 3 H-thymidine as described in H.C.J. Ertl et al, Eur. J. Immunol., 21:1-10 (1991). Furthermore, mouse fibroblasts infected with the Adrab.gp recombinant virus were rendered susceptible to lysis by rabies virus G protein induced H-2 compatible cytolytic T cells.

25

30

Together these *in vitro* experiments demonstrated that Adrab.gp causes expression of the rabies virus G protein in a form that is readily recognized by both rabies virus-specific antibodies and T

cells of the helper and the cytolytic subset. Specifically, Fig. 2 illustrates that Adrab.gp induces proliferation of a rabies virus G protein T helper cell clone in the presence of antigen presenting cells.

5 Example 3 - Immunization Studies

In the next set of experiments, mice were immunized with the Adrab.gp recombinant virus at several doses using different routes of immunization as follows. Groups of eight to twelve week old outbred ICR [Harlan
10 Sprague-Dawley (Indianapolis, IN)] or C3H/He mice [The Jackson Laboratories (Bar Harbor, ME)] were injected subcutaneously (s.c.), orally (per os), intranasally (i.n.), or upon anesthesia and surgical exposure of the trachea intratracheally (i.t.), with the recombinant
15 adenoviruses of the previous examples diluted in 100 to 150 μ l of saline. VRG [which had been propagated on HeLa cells as described in T. J. Wiktor et al, Proc. Natl. Acad. Sci. USA, 81:7194-7198 (1984)] was given s.c. Mice were bled by retro-orbital puncture in regular intervals
20 after immunization to assess serum antibody titers.

The challenge virus standard (CVS)-24 strain of rabies virus, that is antigenically closely related to the ERA strain but shows higher virulence in mice, was derived from brain suspensions of infected newborn ICR
25 mice [T.J. Wiktor et al, J. Virol., 21:626-633 (1977)]. Mice were challenged with 10 mean lethal doses (LD_{50}) of CVS-24 virus given intramuscularly (i.m.) into the masseter muscle; they were observed for the following 3
30 weeks for symptoms indicative of a rabies virus infection. Mice that developed complete bilateral hind leg paralysis (proceeding death by 24 to 48 hours) were euthanized for humanitarian reasons.

A. Virus Neutralizing Antibodies

Groups of ICR mice were immunized in three separate experiments with the different recombinant viruses given at the doses in Table 1 below either i.m., i.n., i.t., or per os. Mice inoculated into the trachea or i.n. were anesthetized prior to vaccination. Mice were bled 10 to 14 days later after a single immunization and serum antibody titers to rabies virus were tested by a neutralization assay. Virus neutralizing antibody (VNA) titers were determined on BHK-21 cells using infectious ERA virus at 1 pfu per cell [B.D. Dietzschold et al, Virology, 161:29-36 (1987)].

Table 1 below illustrates the data expressed as neutralization titers which are the reciprocal of the serum dilution resulting in a 50% reduction in the number of infected cells. Samples were assayed in duplicate in serial 3-fold dilutions starting with a dilution of 1:5. Standard deviations were within 10% for any given experiment.

As illustrated by the results in Table 1, virus given s.c., i.t., or i.n. induced a potent neutralizing antibody response if given at 10^6 pfu. Oral immunization with Adrab.gp or systemic immunization with H5.020CMVlacZ failed to induce a measurable antibody response to rabies virus. The antibody responses to different doses of the recombinant replication-defective Adrab.gp were clearly superior to the response induced by the VRG recombinant. For example, the antibody titers of mice inoculated with as little as 2×10^4 pfu of Adrab.gp were more than 10 times higher than those of mice infected with 2×10^6 pfu of VRG (Table 1).

Table 1
Adrab.gp Recombinant Induces Neutralizing Antibodies
to Rabies Virus

5	Vaccine	Dose	Route of Immunizat'n	Time After	VNA titer Immunizat'n
10	Adrab.gp	2×10^6	s.c.	day 10	3,645
	Adrab.gp	2×10^5	s.c.	day 10	405
	Adrab.gp	2×10^4	s.c.	day 10	405
	VRG	2×10^6	s.c.	day 10	45
	VRG	2×10^5	s.c.	day 10	15
	VRG	2×10^4	s.c.	day 10	5
	None	-	-	day 10	<5
	Adrab.gp	10^4	s.c.	day 14	1,215
	Adrab.gp	10^3	s.c.	day 14	405
	Adrab.gp	10^2	s.c.	day 14	<5
15	Adrab.gp	10^6	i.n.	day 14	1,215
	Adrab.gp	10^6	i.t.	day 14	3,645
	Adrab.gp	10^6	per os	day 14	<5
	None	-	-	-	<5

To ensure that the antibody response was caused by infection recombinant virus rather than by G protein fragments contaminating the virus-containing tissue culture supernatant used for immunization, mice were vaccinated with an equal dose of PFUs of unpurified and gradient purified recombinant adenovirus. Both groups of mice developed identical virus neutralizing antibody titers.

B. Cell-mediated Cytolysis

In addition to neutralizing antibodies, mice inoculated s.c. with Adrab.gp virus developed rabies virus G protein-specific cytolytic T cells able to kill H-2 compatible L929 target cells stably transfected with a plasmid vector expressing the rabies virus G protein under the control of the SV40 early promoter [Z. Q. Xiang et al, J. Virol. Meth., 47:103-116 (1994)].

L929 mouse fibroblasts were maintained in Dulbecco's minimal essential medium (DMEM) supplemented with 10% fetal bovine serum (FBS), HEPES buffer and antibiotics in a 10% CO₂ incubator. L929 cells stably transfected with pSG5rab.gp [S.R. Burger et al, cited above], expressing the rabies virus G protein as well as L929 cells transfected with pSV2neo [ATCC Accession No. 37149] were maintained in 10% DMEM supplemented with 10% FBS. These cell lines used as target cells for cell-mediated cytotoxicity assays have been described in detail previously [Z.Q. Xiang et al, J. Virol. Meth., 47:103-116 (1994)].

Briefly, splenocytes were harvested from immunized C3H/He mice. Single cells were prepared and incubated at 6×10^6 cells per well with 1 pfu per cell of the Adrab.gp recombinant virus in 1.6 ml of DMEM supplemented with 10^{-6} M 2-mercaptoethanol and 2% FBS for 5 days in a humidified 10% CO₂ incubator. The effector cells were then co-cultured with ⁵¹Cr-labeled L929 cells expressing the rabies virus G protein upon stable transfection with the pSG5rab.gp vector at varied effector-to-target cells ratios. To assess spontaneous release, ⁵¹Cr-labeled target cells were incubated with medium; to determine maximal release target cells were co-cultured with 10% sodium dodecyl sulfate. Cell-free supernatants were harvested 4 hours later and radioactivity was measured. Percentage of specific lysis was calculated by using the formula [Y. Yang et al, Immunity, 1:433-442 (1994)]:

$$100 \times \frac{[(\text{Release in presence of effectors} - \text{spontaneous release}) / (\text{Maximal release} - \text{spontaneous release})]}{1}$$

The results are illustrated graphically in Fig. 3A, which illustrates that the Adrab.gp construct induces cytotoxic T cells to the rabies virus G protein.

See, also the results of Fig. 3B, in which lymphocytes were tested at different E:T ratios on an L929 cell line transfected with Adrab.gp or a neomycin expressing control.

5 Example 4 - Challenge Studies

Four different experiments were conducted in which mice, immunized as described in Example 3A above, were challenged with 10 LD₅₀ of rabies virus. Briefly, mice immunized with the Adrab.gp or the VRG recombinant virus were challenged 2 to 5 weeks after immunization with 10 LD₅₀ of the virulent CVS-24 strain of rabies virus given i.m. into the masseter muscle. Mice that subsequently developed complete bilateral hind leg paralysis indicative of a terminal rabies virus infection were euthanized for humanitarian reasons. Survivors were observed for a total of 21 days.

The results are illustrated in Table 2 below. Mice immunized with Adrab.gp i.m., i.t., or i.n. using doses ranging from 10⁴ to 2 x 10⁶ pfu were fully protected against infection; 87% of mice inoculated with 10³ pfu were protected. All mice immunized with only 10² pfu of the recombinant adenovirus or inoculated with the H5.020CMVlacZ control virus (2 x 10⁶ pfu) or with Adrab.gp per os developed a fatal rabies virus encephalitis within 10 days after infection. Mice vaccinated with VRG showed partial protection; the group receiving the highest dose, i.e., 2 x 10⁶ pfu, had a mortality rate above 50% raising to ~90% in mice inoculated with 2 x 10⁴ pfu of VRG.

Table 2

Adrab.gp Recombinant Virus Induces Protective Immunity to
Challenge with Rabies Virus

5	Vaccine	Dose	Route of immunization	% mortality
10	Adrab.gp	2×10^6	s.c.	0
	H5.010CMVlacZ	2×10^6	s.c.	90
	Adrab.gp	2×10^6	s.c.	0
	Adrab.gp	2×10^5	s.c.	0
	Adrab.gp	2×10^4	s.c.	0
15	VRG	2×10^6	s.c.	56
	VRG	2×10^5	s.c.	71
	VRG	2×10^4	s.c.	86
	None	-	-	100
20	Adrab.gp	10^4	s.c.	0
	Adrab.gp	10^3	s.c.	13
	Adrab.gp	10^2	s.c.	100
	None	-	-	100
	Adrab.gp	10^6	i.n.	0
25	Adrab.gp	10^6	i.t.	0
	Adrab.gp	10^6	per os	100
	None	-	-	100

Example 5 - Comparison Studies

The relationship between the magnitude of an immune response and the amount of antigen available to induce naive T and B cells was studied. As determined by immunofluorescence and subsequent analysis by FACS (Figs. 4A-4L), both the VRG and the Adrab.gp recombinants express comparable levels of the rabies virus G protein but the kinetics of expression are different. Cells infected with the VRG virus express high levels of G protein within 12 hours after infection; these levels increased over the next day. By 60 hours the VRG virus

has completely lysed a cell population infected with ~1 pfu of virus per cell.

The same cell line infected with 1 pfu of Adrab.gp per cell shows low expression of the rabies virus G protein on day 1. The level of expression increases until days 3 to 4 after infection and then reaches plateau levels (data shown for days 1 to 3 in Fig. 4A through Fig. 4L). The replication-defective recombinant adenoviruses are non-lytic and maintain stable infection and expression of virus-encoded proteins for extended periods of time. In tissue culture, expression has been shown for 7 days *in vivo*; using the H5.010CMVlacZ recombinant virus, stable levels of expression were demonstrated in immunocompromised mice for 10 months.

A non-lytic virus, e.g., the recombinant replication defective adenovirus, that expresses antigens for prolonged periods of time might thus be more immunogenic compared to a replicating agent that causes death of the infected cells within 24 to 48 hours, e.g., vaccinia.

To substantiate this hypothesis, the inventors compared the immune response to rabies proteins upon immunization of mice with a replication-defective E1 deleted adenovirus and a replication-competent adenovirus. Both adenoviruses were of the human strain 5 and both were deleted in E3. These recombinant viruses were tested by enzyme linked immunoadsorbent assay (ELISA) (Figs. 5A and 5B). The ELISAs were conducted in 96-well microtiter plates coated with 0.1 to 0.2 μ g per well of ERA-BPL virus or 1-2 μ g per well of purified H5.010CMVlacZ virus, using an alkaline phosphatase conjugated goat anti-mouse Ig as second antibody as described in detail in Xiang and Ertl, Virus Res., 24:297-314 (1992). As shown in Figs. 5A and 5B, the

antibody response to the E1 deleted Adrab.gp virus (solid box) was superior to that of a replication competent Ad virus (open box). This supports the position that long-term expression of viral antigens by a non-lytic virus can induce stronger immune response compared to short-term expression by a replication-competent agent. Figs. 5A and 5B illustrate that expression of E1 causes a reduction in the antibody response to adenovirus.

These studies demonstrate that the recombinant replication-defective adenovirus used in the present invention shows higher immunogenicity compared to a replication-competent adenovirus. Without wishing to be bound by theory, it is believed that the length of expression of the antigen plays a role in induction of the immune response. In similar studies comparing the replication defective adenovirus vaccine to the VRG vaccine, the Ad vaccine expresses the rabies antigen longer than the VRG recombinant virus vaccine.

Example 6 - Further Comparative Studies

The following study was performed to test if pre-existing immunity to adenoviral proteins interferes with stimulation of a rabies G protein-specific immune response to the Adrab.gp construct. Groups of C3H/He mice were immunized with 10^5 or 10^6 pfu of a replication-competent adenovirus human serotype 5 that had been deleted of the E3 gene. Mice were injected 4 weeks later with 10^6 pfu of Adrab.gp. Control mice were only injected with Adrab.gp (10^6 pfu). Mice were bled 12 days later and neutralizing antibody titers were determined (Table 3).

Table 3

The Effect of Pre-Existing Immunity to Adenovirus on the Rabies VNA Response to the Adrab.gp Vaccine

5	Pre-immunization Titer	Immunization	VNA
	None	10^6 pfu Adrab.gp	3.645
	10^5 pfu Ad5d17001	10^6 pfu Adrab.gp	3.645
10	10^6 pfu Ad517001	10^6 pfu Adrab.gp	1.215
	None	None	<5

Mice pre-immunized with adenovirus developed VNA to rabies virus upon booster immunization with the Adrab.gp construct. Titers were equivalent, or marginally lower, when compared to those in control mice that had only received Adrab.gp, indicating that antibodies to adenoviruses only marginally inhibit the B cell response to proteins expressed by adenovirus recombinants. When tested in comparison to a reference serum provided by the World Health Organization, sera from pre-immune (both doses of adenovirus) or naive mice were shown to have titers of 40 IU to rabies virus. Protection to rabies virus is correlated to antibody titers and 2 IU are considered sufficient to protect against a severe challenge. Pre-immunity to adenovirus does, thus, not impair the ability of the Adrab.gp vaccine to elicit protective immunity.

Similar data were obtained for the stimulation of cytolytic T cells to rabies virus-infected cells, pre-immune animals showed somewhat lower lysis compared to the control group (see Figs. 6A and 6B). Figs. 6A and 6B illustrate that the cytolytic T cell response to rabies virus G protein expressing target cells upon immunization with Adrab.gp is only slightly reduced in animals immune

to adenovirus. Nevertheless, adenovirus-immune mice still developed significant T cell responses to the rabies virus G protein upon immunization with Adrab.gp.

Example 7 - Additional Challenge Studies

5 In this experiment the kinetic of the induction of protective immunity upon vaccination was tested with the Adrab.gp virus. Vaccination to rabies virus is in general given post-exposure, hence it is crucial for the vaccine to induce a rapid immune response before the
10 rabies virus has reached the central nervous system.

 Mice were immunized with 10^6 PFU of Adrab.gp s.c. Immunized mice were challenged 3 (\diamond), 7 (\square), and 10 (\blacksquare) days after vaccination with 10 LD₅₀ of rabies virus given i.m. Naive mice (X) served as controls. Mice were
15 observed for four weeks to record mortality. As shown in Fig. 7, mice vaccinated with Adrab.gp virus 10 days previously were completely protected; while more than half of the animals were protected as early as seven days after a single injection. Mice vaccinated three days
20 before challenge succumbed to the infection.

 Numerous modifications and variations of the present invention are included in the above-identified specification and are expected to be obvious to one of skill in the art. Such modifications and alterations to
25 the compositions and processes of the present invention are believed to be encompassed in the scope of the claims appended hereto.

SEQUENCE LISTING

(1) GENERAL INFORMATION:

- (i) APPLICANT: Wistar Institute of Anatomy and Biology
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Ertl, Hildegund C.J.
Wilson, James M.
- (ii) TITLE OF INVENTION: A Replication-Defective
Adenovirus Human Type 5
Recombinant as a Vaccine Carrier
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 - (B) COMPUTER: IBM PC compatible
 - (C) OPERATING SYSTEM: PC-DOS/MS-DOS
 - (D) SOFTWARE: PatentIn Release #1.0, Version #1.30
- (vi) CURRENT APPLICATION DATA:
 - (A) APPLICATION NUMBER: WO
 - (B) FILING DATE:
 - (C) CLASSIFICATION:
- (vii) PRIOR APPLICATION DATA:
 - (A) APPLICATION NUMBER: US 08/461,837
 - (B) FILING DATE: 05-JUN-1995
- (vii) PRIOR APPLICATION DATA:
 - (A) APPLICATION NUMBER: US 60/000,078
 - (B) FILING DATE: 08-JUN-1995
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35

(2) INFORMATION FOR SEQ ID NO:1:

- (i) SEQUENCE CHARACTERISTICS:
 (A) LENGTH: 8236 base pairs
 (B) TYPE: nucleic acid
 (C) STRANDEDNESS: double
 (D) TOPOLOGY: not relevant

(ii) MOLECULE TYPE: cDNA

- (ix) FEATURE:
 (A) NAME/KEY: CDS
 (B) LOCATION: 1185..2756

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:1:

GAATTCGCTA GCATCATCAA TAATATACCT TATTTTGGAT TGAAGCCAAT	50
ATGATAATGA GGGGGTGGAG TTTGTGACGT GGCGCGGGGC GTGGGAACGG	100
GGCGGGTGAC GTAGTAGTGT GGCGGAAGTG TGATGTTGCA AGTGTGGCGG	150
AACACATGTA AGCGACGGAT GTGGCAAAAG TGACGTTTTT GGTGTGCGCC	200
GGTGTACACA GGAAGTGACA ATTTTCGCGC GGTTTTAGGC GGATGTTGTA	250
GTAAATTTGG GCGTAACCGA GTAAGATTG GCCATTTTCG CGGGAAAACT	300
GAATAAGAGG AAGTGAAATC TGAATAATTT TGTGTTACTC ATAGCGCGTA	350
ATATTTGTCT AGGGAGATCA GCCTGCAGGT CGTTACATAA CTTACGGTAA	400
ATGGCCCGCC TGGCTGACCG CCAACGACC CCCGCCCAT TACGTCAATA	450
ATGACGTATG TTCCCATAGT AACGCCAATA GGGACTTTCC ATTGACGTCA	500
ATGGGTGGAG TATTTACGGT AACTGCCCA CTTGGCAGTA CATCAAGTGT	550
ATCATATGCC AAGTACGCCC CCTATTGACG TCAATGACGG TAAATGGCCC	600
GCCTGGCATT ATGCCAGTA CATGACCTTA TGGGACTTTC CTA CTGTTGGCA	650
GTACATCTAC GTATTAGTCA TCGCTATTAC CATGGTGATG CGGTTTTGGC	700
AGTACATCAA TGGGCGTGGA TAGCGGTTTG ACTCACGGGG ATTTCCAAGT	750
CTCCACCCCA TTGACGTCAA TGGGAGTTTG TTTTGGCACC AAAATCAACG	800
GGACTTTCCA AAATGTCGTA ACAACTCCGC CCCATTGACG CAAATGGGCG	850
GTAGGCGTGT ACGGTGGGAG GTCTATATAA GCAGAGCTCG TTTAGTGAAC	900

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CGTCAGATCG	CCTGGAGACG	CCATCCACGC	TGTTTTGACC	TCCATAGAAG	950
ACACCGGGAC	CGATCCAGCC	TCCGGACTCT	AGAGGATCCG	GTACTCGAGG	1000
AACTGAAAAA	CCAGAAAGTT	AACTGGTAAG	TTTAGTCTTT	TTGTCTTTTA	1050
TTTCAGGTCC	CGGATCCGGT	GGTGGTGCAA	ATCAAAGAAC	TGCTCCTCAG	1100
TGGATGTTGC	CTTTACTTCT	AGGCCTGTAC	GGAAGTGTTA	CTTCTGCTCT	1150
AAAAGCTGCG	GAATTGTACC	CGCGGCCAGG	AAAG ATG GTT CCT CAG	1196	
			Met Val Pro Gln		
			1		
GCT CTC CTG TTT GTA CCC CTT CTG GTT TTT CCA TTG TGT TTT	1238				
Ala Leu Leu Phe Val Pro Leu Leu Val Phe Pro Leu Cys Phe					
5 10 15					
GGG AAA TTC CCT ATT TAC ACG ATA CTA GAC AAG CTT GGT CCC	1280				
Gly Lys Phe Pro Ile Tyr Thr Ile Leu Asp Lys Leu Gly Pro					
20 25 30					
TGG AGC CCG ATT GAC ATA CAT CAC CTC AGC TGC CCA AAC AAT	1322				
Trp Ser Pro Ile Asp Ile His His Leu Ser Cys Pro Asn Asn					
35 40 45					
TTG GTA GTG GAG GAC GAA GGA TGC ACC AAC CTG TCA GGG TTC	1364				
Leu Val Val Glu Asp Glu Gly Cys Thr Asn Leu Ser Gly Phe					
50 55 60					
TCC TAC ATG GAA CTT AAA GTT GGA TAC ATC TTA GCC ATA AAA	1406				
Ser Tyr Met Glu Leu Lys Val Gly Tyr Ile Leu Ala Ile Lys					
65 70					
ATG AAC GGG TTC ACT TGC ACA GGC GTT GTG ACG GAG GCT GAA	1448				
Met Asn Gly Phe Thr Cys Thr Gly Val Val Thr Glu Ala Glu					
75 80 85					
ACC TAC ACT AAC TTC GTT GGT TAT GTC ACA ACC ACG TTC AAA	1490				
Thr Tyr Thr Asn Phe Val Gly Tyr Val Thr Thr Thr Phe Lys					
90 95 100					
AGA AAG CAT TTC CGC CCA ACA CCA GAT GCA TGT AGA GCC GCG	1532				
Arg Lys His Phe Arg Pro Thr Pro Asp Ala Cys Arg Ala Ala					
105 110 115					
TAC AAC TGG AAG ATG GCC GGT GAC CCC AGA TAT GAA GAG TCT	1574				
Tyr Asn Trp Lys Met Ala Gly Asp Pro Arg Tyr Glu Glu Ser					
120 125 130					

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CTA Leu	CAC His	AAT Asn	CCG Pro	TAC Tyr	CCT Pro	GAC Asp	TAC Tyr	CGC Arg	TGG Trp	CTT Leu	CGA Arg	ACT Thr	GTA Val	1616
				135					140					
AAA Lys	ACC Thr	ACC Thr	AAG Lys	GAG Glu	TCT Ser	CTC Leu	GTT Val	ATC Ile	ATA Ile	TCT Ser	CCA Pro	AGT Ser	GTA Val	1658
145					150					155				
GCA Ala	GAT Asp	TTG Leu	GAC Asp	CCA Pro	TAT Tyr	GAC Asp	AGA Arg	TCC Ser	CTT Leu	CAC His	TCG Ser	AGG Arg	GTC Val	1700
	160					165					170			
TTC Phe	CCT Pro	AGC Ser	GGG Gly	AAG Lys	TGC Cys	TCA Ser	GGA Gly	GTA Val	GCG Ala	GTG Val	TCT Ser	TCT Ser	ACC Thr	1742
		175					180					185		
TAC Tyr	TGC Cys	TCC Ser	ACT Thr	AAC Asn	CAC His	GAT Asp	TAC Tyr	ACC Thr	ATT Ile	TGG Trp	ATG Met	CCC Pro	GAG Glu	1784
			190					195					200	
AAT Asn	CCG Pro	AGA Arg	CTA Leu	GGG Gly	ATG Met	TCT Ser	TGT Cys	GAC Asp	ATT Ile	TTT Phe	ACC Thr	AAT Asn	AGT Ser	1826
				205					210					
AGA Arg	GGG Gly	AAG Lys	AGA Arg	GCA Ala	TCC Ser	AAA Lys	GGG Gly	AGT Ser	GAG Glu	ACT Thr	TGC Cys	GGC Gly	TTT Phe	1868
215					220					225				
GTA Val	GAT Asp	GAA Glu	AGA Arg	GGC Gly	CTA Leu	TAT Tyr	AAG Lys	TCT Ser	TTA Leu	AAA Lys	GGA Gly	GCA Ala	TGC Cys	1910
	230					235					240			
AAA Lys	CTC Leu	AAG Lys	TTA Leu	TGT Cys	GGA Gly	GTT Val	CTA Leu	GGA Gly	CTT Leu	AGA Arg	CTT Leu	ATG Met	GAT Asp	1952
		245					250					255		
GGA Gly	ACA Thr	TGG Trp	GTC Val	GCG Ala	ATG Met	CAA Gln	ACA Thr	TCA Ser	AAT Asn	GAA Glu	ACC Thr	AAA Lys	TGG Trp	1994
			260					265					270	
TGC Cys	CCT Pro	CCC Pro	GAT Asp	CAG Gln	TTG Leu	GTG Val	AAC Asn	CTG Leu	CAC His	GAC Asp	TTT Phe	CGC Arg	TCA Ser	2036
				275					280					
GAC Asp	GAA Glu	ATT Ile	GAG Glu	CAC His	CTT Leu	GTT Val	GTA Val	GAG Glu	GAG Glu	TTG Leu	GTC Val	AGG Arg	AAG Lys	2078
285					290					295				
AGA Arg	GAG Glu	GAG Glu	TGT Cys	CTG Leu	GAT Asp	GCA Ala	CTA Leu	GAG Glu	TCC Ser	ATC Ile	ATG Met	ACA Thr	ACC Thr	2120
	300					305					310			

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AAG	TCA	GTG	AGT	TTC	AGA	CGT	CTC	AGT	CAT	TTA	AGA	AAA	CTT	2162
Lys	Ser	Val	Ser	Phe	Arg	Arg	Leu	Ser	His	Leu	Arg	Lys	Leu	
		315					320					325		
GTC	CCT	GGG	TTT	GGA	AAA	GCA	TAT	ACC	ATA	TTC	AAC	AAG	ACC	2204
Val	Pro	Gly	Phe	Gly	Lys	Ala	Tyr	Thr	Ile	Phe	Asn	Lys	Thr	
			330					335					340	
TTG	ATG	GAA	GCC	GAT	GCT	CAC	TAC	AAG	TCA	GTC	AGA	ACT	TGG	2246
Leu	Met	Glu	Ala	Asp	Ala	His	Tyr	Lys	Ser	Val	Arg	Thr	Trp	
				345					350					
AAT	GAG	ATC	CTC	CCT	TCA	AAA	GGG	TGT	TTA	AGA	GTT	GGG	GGG	2288
Asn	Glu	Ile	Leu	Pro	Ser	Lys	Gly	Cys	Leu	Arg	Val	Gly	Gly	
355					360					365				
AGG	TGT	CAT	CCT	CAT	GTG	AAC	GGG	GTG	TTT	TTC	AAT	GGT	ATA	2330
Arg	Cys	His	Pro	His	Val	Asn	Gly	Val	Phe	Phe	Asn	Gly	Ile	
		370				375					380			
ATA	TTA	GGA	CCT	GAC	GGC	AAT	GTC	TTA	ATC	CCA	GAG	ATG	CAA	2372
Ile	Leu	Gly	Pro	Asp	Gly	Asn	Val	Leu	Ile	Pro	Glu	Met	Gln	
		385					390					395		
TCA	TCC	CTC	CTC	CAG	CAA	CAT	ATG	GAG	TTG	TTG	GAA	TCC	TCG	2414
Ser	Ser	Leu	Leu	Gln	Gln	His	Met	Glu	Leu	Leu	Glu	Ser	Ser	
			400					405					410	
GTT	ATC	CCC	CTT	GTG	CAC	CCC	CTG	GCA	GAC	CCG	TCT	ACC	GTT	2456
Val	Ile	Pro	Leu	Val	His	Pro	Leu	Ala	Asp	Pro	Ser	Thr	Val	
				415					420					
TTC	AAG	GAC	GGT	GAC	GAG	GCT	GAG	GAT	TTT	GTT	GAA	GTT	CAC	2498
Phe	Lys	Asp	Gly	Asp	Glu	Ala	Glu	Asp	Phe	Val	Glu	Val	His	
425					430					435				
CTT	CCC	GAT	GTG	CAC	AAT	CAG	GTC	TCA	GGA	GTT	GAC	TTG	GGT	2540
Leu	Pro	Asp	Val	His	Asn	Gln	Val	Ser	Gly	Val	Asp	Leu	Gly	
		440				445					450			
CTC	CCG	AAC	TGG	GGG	AAG	TAT	GTA	TTA	CTG	AGT	GCA	GGG	GCC	2582
Leu	Pro	Asn	Trp	Gly	Lys	Tyr	Val	Leu	Leu	Ser	Ala	Gly	Ala	
		455					460					465		
CTG	ACT	GCC	TTG	ATG	TTG	ATA	ATT	TTC	CTG	ATG	ACA	TGT	TGT	2624
Leu	Thr	Ala	Leu	Met	Leu	Ile	Ile	Phe	Leu	Met	Thr	Cys	Cys	
			470					475					480	
AGA	AGA	GTC	AAT	CGA	TCA	GAA	CCT	ACG	CAA	CAC	AAT	CTC	AGA	2666
Arg	Arg	Val	Asn	Arg	Ser	Glu	Pro	Thr	Gln	His	Asn	Leu	Arg	
				485					490					

GGG ACA GGG AGG GAG GTG TCA GTC ACT CCC CAA AGC GGG AAG Gly Thr Gly Arg Glu Val Ser Val Thr Pro Gln Ser Gly Lys 495 500 505	2708
ATC ATA TCT TCA TGG GAA TCA CAC AAG AGT GGG GGT GAG ACC Ile Ile Ser Ser Trp Glu Ser His Lys Ser Gly Gly Glu Thr 510 515 520	2750
AGA CTG TGAGGACTGG CCGTCCTTTC AACGATCCAA GTCCTGAAGA Arg Leu	2796
TCACCTCCCC TTGGGGGGTT CTTTTTAAAA AGGCCGCGGG GATCCAGACA	2846
TGATAAGATA CATTGATGAG TTTGGACAAA CCACAAC TAG AATGCAGTGA	2896
AAAAAATGCT TTATTTGTGA AATTTGTGAT GCTATTGCTT TATTTGTAAC	2946
CATTATAAGC TGCAATAAAC AAGTTAACAA CAACAATTGC ATTCATTTTA	2996
TGTTTCAGGT TCAGGGGGAG GTGTGGGAGG TTTTTCGGA TCCTCTAGAG	3046
TCGACCTGCA GGCTGATCTG GAAGGTGCTG AGGTACGATG AGACCCGCAC	3096
CAGGTGCAGA CCCTGCGAGT GTGGCGGTAA ACATATTAGG AACCAGCCTG	3146
TGATGCTGGA TGTGACCGAG GAGCTGAGGC CCGATCACTT GGTGCTGGCC	3196
TGCACCCGCG CTGAGTTTGG CTCTAGCGAT GAAGATACAG ATTGAGGTAC	3246
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GTCTTATGTA GTTTTGTATC TGTTTTCGAG CAGCCGCCGC CGCCATGAGC	3346
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GACGCCCTTG TGACCTCAA GATTTTCCAT GCATTCGTCC ATAATGATGG	4346
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GGGCGTAGTT ACCCTCACAG ATTTGCATTT CCCACGCTTT GAGTTCAGAT	4546
GGGGGGATCA TGTCTACCTG CGGGGCGATG AAGAAAACGG TTTCCGGGGT	4596
AGGGGAGATC AGCTGGGAAG AAAGCAGGTT CCTGAGCAGC TGCGACTTAC	4646
CGCAGCCGGT GGGCCCGTAA ATCACACCTA TTACCGGGTG CAACTGGTAG	4696
TTAAGAGAGC TGCAGCTGCC GTCATCCCTG AGCAGGGGGG CCACTTCGTT	4746
AAGCATGTCC CTGACTCGCA TGTTTTCCCT GACCAAATCC GCCAGAAGGC	4796
GCTCGCCGCC CAGCGATAGC AGTTCTTGCA AGGAAGCAAA GTTTTTCAAC	4846
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TTCCAGGCGG TCCCACAGCT CGGTCACCTG CTCTACGGCA TCTCGATCCA	4946
GCATATCTCC TCGTTTCGCG GGTGCGGGCG GCTTTCGCTG TACGGCAGTA	4996
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GTCCTCGTCA GCGTAGTCTG GGTCACGGTG AAGGGGTGCG CTCCGGGCTG	5096

CGCGCTGGCC	AGGGTGCCT	TGAGGCTGGT	CCTGCTGGTG	CTGAAGCGCT	5146
GCCGGTCTTC	GCCCTGCGCG	TCGGCCAGGT	AGCATTTGAC	CATGGTGTCA	5196
TAGTCCAGCC	CCTCCGCGGC	GTGGCCCTTG	GCGCGCAGCT	TGCCCTTGA	5246
GGAGGCGCCG	CACGAGGGGC	AGTGCAGACT	TTTGAGGGCG	TAGAGCTTGG	5296
GCGCGAGAAA	TACCGATTCC	GGGGAGTAGG	CATCCGCGCC	GCAGGCCCCG	5346
CAGACGGTCT	CGCATTCCAC	GAGCCAGGTG	AGCTCTGGCC	GTTCTGGGGTC	5396
AAAAACCAGG	TTTCCCCCAT	GCTTTTGTAT	GCGTTTCTTA	CCTCTGGTTT	5446
CCATGAGCCG	GTGTCCACGC	TCGGTGACGA	AAAGGCTGTC	CGTGTCCCCG	5496
TATACAGACT	TGAGAGGCCT	GTCCTCGACC	GATGCCCTTG	AGAGCCTTCA	5546
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CTTATGACTG	TCTTCTTTAT	CATGCAACTC	GTAGGACAGG	TGCCGGCAGC	5646
GCTCTGGGTC	ATTTTCGGCG	AGGACCGCTT	TCGCTGGAGC	GCGACGATGA	5696
TCGGCCTGTC	GCTTGCGGTA	TTCGGAATCT	TGCACGCCCT	CGCTCAAGCC	5746
TTCGTCACTG	GTCCCGCCAC	CAAACGTTTC	GGCGAGAAGC	AGGCCATTAT	5796
CGCCGGCATG	GCGGCCGACG	CGCTGGGCTA	CGTCTTGCTG	GCGTTCGCGA	5846
CGCGAGGCTG	GATGGCCTTC	CCCATTATGA	TTCTTCTCGC	TTCCGGCGGC	5896
ATCGGGATGC	CCGCGTTGCA	GGCCATGCTG	TCCAGGCAGG	TAGATGACGA	5946
CCATCAGGGA	CAGCTTCAAG	GATCGCTCGC	GGCTCTTACC	AGCCTAACTT	5996
CGATCACTGG	ACCGCTGATC	GTCACGGCGA	TTTATGCCGC	CTCGGCGAGC	6046
ACATGGAACG	GGTTGGCATG	GATTGTAGGC	GCCGCCCTAT	ACCTTGCTCTG	6096
CCTCCCCGCG	TTGCGTCGCG	GTGCATGGAG	CCGGGCCACC	TCGACCTGAA	6146
TGGAAGCCGG	CGGCACCTCG	CTAACGGATT	CACCACTCCA	AGAATTGGAG	6196
CCAATCAATT	CTTGCGGAGA	ACTGTGAATG	CGCAAACCAA	CCCTTGGCAG	6246
AACATATCCA	TCGCGTCCGC	CATCTCCAGC	AGCCGCACGC	GGCGCATCTC	6296
GGGCAGCGTT	GGGTCCCTGGC	CACGGGTGCG	CATGATCGTG	CTCCTGTCGT	6346
TGAGGACCCG	GCTAGGCTGG	CGGGGTTGCC	TTACTGGTTA	GCAGAATGAA	6396

TCACCGATAC GCGAGCGAAC GTGAAGCGAC TGCTGCTGCA AAACGTCTGC	6446
GACCTGAGCA ACAACATGAA TGGTCTTCGG TTTCCGTGTT TCGTAAAGTC	6496
TGGAAACGCG GAAGTCAGCG CCCTGCACCA TTATGTTCCG GATCTGCATC	6546
GCAGGATGCT GCTGGCTACC CTGTGGAACA CCTACATCTG TATTAACGAA	6596
GCCTTTCTCA ATGCTCACGC TGTAGGTATC TCAGTTCGGT GTAGGTCGTT	6646
CGCTCCAAGC TGGGCTGTGT GCACGAACCC CCCGTTACGC CCGACCGCTG	6696
CGCCTTATCC GGTAACATATC GTCTTGAGTC CAACCCGGTA AGACACGACT	6746
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GTAGGCGGTG CTACAGAGTT CTTGAAGTGG TGGCCTAACT ACGGCTACAC	6846
TAGAAGGACA GTATTTGGTA TCTGCGCTCT GCTGAAGCCA GTTACCTTCG	6896
GAAAAAGAGT TGGTAGCTCT TGATCCGGCA AACAAACCAC CGCTGGTAGC	6946
GGTGGTTTTT TTGTTTGCAA GCAGCAGATT ACGCGCAGAA AAAAAGGATC	6996
TCAAGAAGAT CCTTTGATCT TTTCTACGGG GTCTGACGCT CAGTGAACG	7046
AAAACTCACG TTAAGGGATT TTGGTCATGA GATTATCAAA AAGGATCTTC	7096
ACCTAGATCC TTTTAAATTA AAAATGAAGT TTTAAATCAA TCTAAAGTAT	7146
ATATGAGTAA ACTTGGTCTG ACAGTTACCA ATGCTTAATC AGTGAGGCAC	7196
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TAAACCAGCC AGCCGGAAGG GCCGAGCGCA GAAGTGGTCC TGCAACTTTA	7396
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CGATCAAGGC GAGTTACATG ATCCCCCATG TTGTGCAAAA AAGCGGTTAG	7596
CTCCTTCGGT CCTCCGATCG TTGTCAGAAG TAAGTTGGCC GCAGTGTTAT	7646
CACTCATGGT TATGGCAGCA CTGCATAATT CTCTTACTGT CATGCCATCC	7696

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GTAAGATGCT	TTTCTGTGAC	TGGTGAGTAC	TCAACCAAGT	CATTCTGAGA	7746
ATAGTGTATG	CGGCGACCGA	GTTGCTCTTG	CCCGGCGTCA	ACACGGGATA	7796
ATACCGCGCC	ACATAGCAGA	ACTTTAAAAG	TGCTCATCAT	TGGAAAACGT	7846
TCTTCGGGGC	GAAAACTCTC	AAGGATCTTA	CCGCTGTTGA	GATCCAGTTC	7896
GATGTAACCC	ACTCGTGCAC	CCAACTGATC	TTCAGCATCT	TTTACTTTCA	7946
CCAGCGTTTC	TGGGTGAGCA	AAAACAGGAA	GGCAAAATGC	CGCAAAAAAG	7996
GGAATAAGGG	CGACACGGAA	ATGTTGAATA	CTCATACTCT	TCCTTTTTCA	8046
ATATTATTGA	AGCATTTATC	AGGGTTATTG	TCTCATGAGC	GGATACATAT	8096
TTGAATGTAT	TTAGAAAAAT	AAACAAATAG	GGGTTCCGCG	CACATTTCCC	8146
CGAAAAGTGC	CACCTGACGT	CTAAGAAACC	ATTATTATCA	TGACATTAAC	8196
CTATAAAAAT	AGGCGTATCA	CGAGGCCCTT	TCGTCTTCAA		8236

(2) INFORMATION FOR SEQ ID NO:2:

(i) SEQUENCE CHARACTERISTICS:

(A) LENGTH: 524 amino acids

(B) TYPE: amino acid

(D) TOPOLOGY: linear

(ii) MOLECULE TYPE: protein

(xi) SEQUENCE DESCRIPTION: SEQ ID NO:2:

Met	Val	Pro	Gln	Ala	Leu	Leu	Phe	Val	Pro	Leu	Leu	Val	Phe	Pro
1				5					10					15
Leu	Cys	Phe	Gly	Lys	Phe	Pro	Ile	Tyr	Thr	Ile	Leu	Asp	Lys	Leu
			20						25					30
Gly	Pro	Trp	Ser	Pro	Ile	Asp	Ile	His	His	Leu	Ser	Cys	Pro	Asn
			35						40					45
Asn	Leu	Val	Val	Glu	Asp	Glu	Gly	Cys	Thr	Asn	Leu	Ser	Gly	Phe
			50						55					60
Ser	Tyr	Met	Glu	Leu	Lys	Val	Gly	Tyr	Ile	Leu	Ala	Ile	Lys	Met
			65						70					75

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Asn Gly Phe Thr Cys Thr Gly Val Val Thr Glu Ala Glu Thr Tyr	80	85	90
Thr Asn Phe Val Gly Tyr Val Thr Thr Thr Phe Lys Arg Lys His	95	100	105
Phe Arg Pro Thr Pro Asp Ala Cys Arg Ala Ala Tyr Asn Trp Lys	110	115	120
Met Ala Gly-Asp Pro Arg Tyr Glu Glu Ser Leu His Asn Pro Tyr	125	130	135
Pro Asp Tyr Arg Trp Leu Arg Thr Val Lys Thr Thr Lys Glu Ser	140	145	150
Leu Val Ile Ile Ser Pro Ser Val Ala Asp Leu Asp Pro Tyr Asp	155	160	165
Arg Ser Leu His Ser Arg Val Phe Pro Ser Gly Lys Cys Ser Gly	170	175	180
Val Ala Val Ser Ser Thr Tyr Cys Ser Thr Asn His Asp Tyr Thr	185	190	195
Ile Trp Met Pro Glu Asn Pro Arg Leu Gly Met Ser Cys Asp Ile	200	205	210
Phe Thr Asn Ser Arg Gly Lys Arg Ala Ser Lys Gly Ser Glu Thr	215	220	225
Cys Gly Phe Val Asp Glu Arg Gly Leu Tyr Lys Ser Leu Lys Gly	230	235	240
Ala Cys Lys Leu Lys Leu Cys Gly Val Leu Gly Leu Arg Leu Met	245	250	255
Asp Gly Thr Trp Val Ala Met Gln Thr Ser Asn Glu Thr Lys Trp	260	265	270
Cys Pro Pro Asp Gln Leu Val Asn Leu His Asp Phe Arg Ser Asp	275	280	285
Glu Ile Glu His Leu Val Val Glu Glu Leu Val Arg Lys Arg Glu	290	295	300
Glu Cys Leu Asp Ala Leu Glu Ser Ile Met Thr Thr Lys Ser Val	305	310	315
Ser Phe Arg Arg Leu Ser His Leu Arg Lys Leu Val Pro Gly Phe	320	325	330

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Gly	Lys	Ala	Tyr	Thr	Ile	Phe	Asn	Lys	Thr	Leu	Met	Glu	Ala	Asp	335	340	345
Ala	His	Tyr	Lys	Ser	Val	Arg	Thr	Trp	Asn	Glu	Ile	Leu	Pro	Ser	350	355	360
Lys	Gly	Cys	Leu	Arg	Val	Gly	Gly	Arg	Cys	His	Pro	His	Val	Asn	365	370	375
Gly	Val	Phe	Phe	Asn	Gly	Ile	Ile	Leu	Gly	Pro	Asp	Gly	Asn	Val	380	385	390
Leu	Ile	Pro	Glu	Met	Gln	Ser	Ser	Leu	Leu	Gln	Gln	His	Met	Glu	395	400	405
Leu	Leu	Glu	Ser	Ser	Val	Ile	Pro	Leu	Val	His	Pro	Leu	Ala	Asp	410	415	420
Pro	Ser	Thr	Val	Phe	Lys	Asp	Gly	Asp	Glu	Ala	Glu	Asp	Phe	Val	425	430	435
Glu	Val	His	Leu	Pro	Asp	Val	His	Asn	Gln	Val	Ser	Gly	Val	Asp	440	445	450
Leu	Gly	Leu	Pro	Asn	Trp	Gly	Lys	Tyr	Val	Leu	Leu	Ser	Ala	Gly	455	460	465
Ala	Leu	Thr	Ala	Leu	Met	Leu	Ile	Ile	Phe	Leu	Met	Thr	Cys	Cys	470	475	480
Arg	Arg	Val	Asn	Arg	Ser	Glu	Pro	Thr	Gln	His	Asn	Leu	Arg	Gly	485	490	495
Thr	Gly	Arg	Glu	Val	Ser	Val	Thr	Pro	Gln	Ser	Gly	Lys	Ile	Ile	500	505	510
Ser	Ser	Trp	Glu	Ser	His	Lys	Ser	Gly	Gly	Glu	Thr	Arg	Leu		515	520	

WHAT IS CLAIMED IS:

1. A recombinant adenovirus comprising an adenovirus containing a complete deletion of its E1 gene and at least a functional deletion of its E3 gene, and, in the site of the E1 gene deletion, a sequence comprising a non-adenovirus promoter directing the replication and expression of DNA encoding a heterologous protein from a disease-causing agent, which, when administered to the animal or human in said recombinant virus, elicits a substantially complete protective immune response against an agent causing said disease at a low dosage.
2. The recombinant adenovirus according to claim 1 wherein said promoter is selected from the group consisting of a cytomegalovirus promoter, an RSV promoter and an SV40 promoter.
3. The recombinant adenovirus according to claim 1, wherein the disease is rabies and the protein is a rabies virus glycoprotein.
4. The recombinant adenovirus according to claim 3, wherein the rabies virus protein is derived from the Evelyn Rockitniki Abelseth rabies strain.
5. The recombinant adenovirus according to claim 1 wherein said heterologous protein is selected from the group consisting of a protein from respiratory syncytial virus, human papilloma virus, or human immunodeficiency virus, and a tumor-associated protein specific for a selected malignancy.

6. The recombinant adenovirus according to claim 1, wherein the disease is human immunodeficiency virus (HIV) infection and the protein is HIV glycoprotein 120.

7. The recombinant adenovirus according to claim 1, wherein the disease is human papilloma virus infection and the protein is selected from the group consisting of E6, E7 and L1, and combinations thereof.

8. The recombinant adenovirus according to claim 1, wherein the disease is respiratory syncytial virus infection and the protein is selected from the group consisting of the glyco- (G) protein and the fusion (F) protein.

9. The recombinant adenovirus according to claim 1, wherein said adenovirus is Adrab.gp.

10. The use of the recombinant adenovirus of claims 1-9 in the manufacture of a pharmaceutical or veterinary product for the prevention or treatment of a disease.

11. A pharmaceutical or veterinary product comprising a recombinant adenovirus of claims 1-9.

12. The product according to claim 11, comprising a single dose of recombinant adenovirus between about 10^4 and about 10^7 pfu.

13. The product according to claim 11, wherein the adenovirus is formulated for either subcutaneous, rectal, intratracheal, intramuscular or intranasal administration.

14. A vaccine composition comprising a recombinant adenovirus comprising an adenovirus containing a complete deletion of its E1 gene and at least a functional deletion of its E3 gene, and, in the site of the E1 gene deletion, a sequence comprising a non-adenovirus promoter directing the replication and expression of DNA encoding a rabies virus G protein, which, when administered to a mammal in said recombinant virus, elicits a substantially complete protective immune response against rabies virus at a low dosage.

15. The composition according to claim 14 wherein said promoter is the CMV enhancer/promoter.

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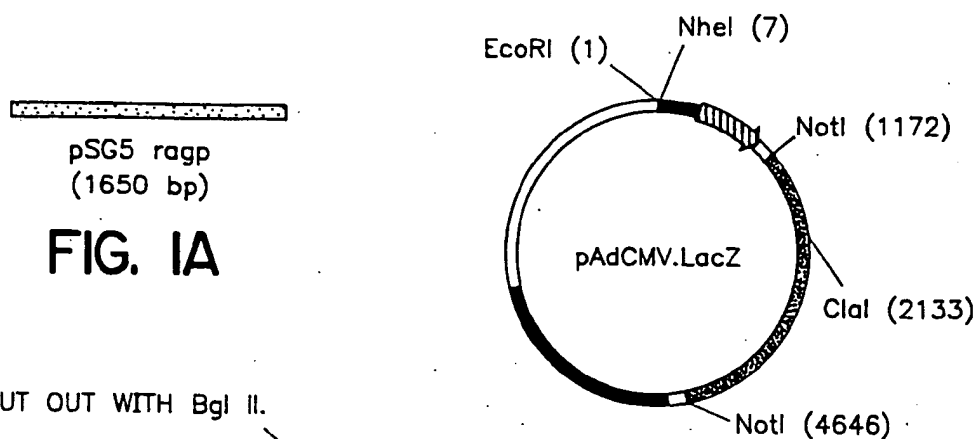
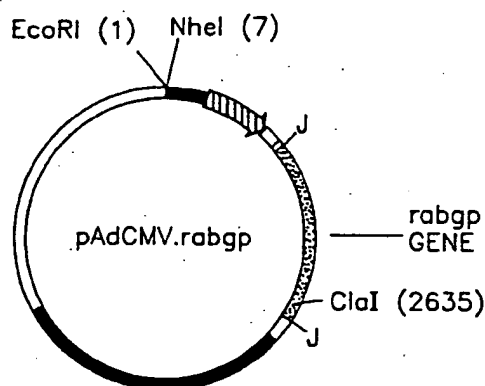


FIG. IA

CUT OUT WITH Bgl II.

CUT pAdCMV.LacZ WITH
Not I TO REMOVE LacZ
GENE

FIG. IB

rabgp GENE INSERTED BY
BLUNT-END CLONING

HOMOLOGOUS RECOMBINATION WITH dI7001

FIG. IC

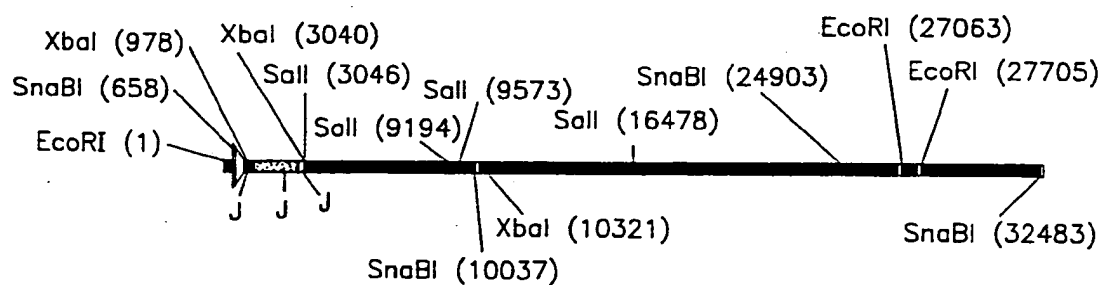


FIG. ID

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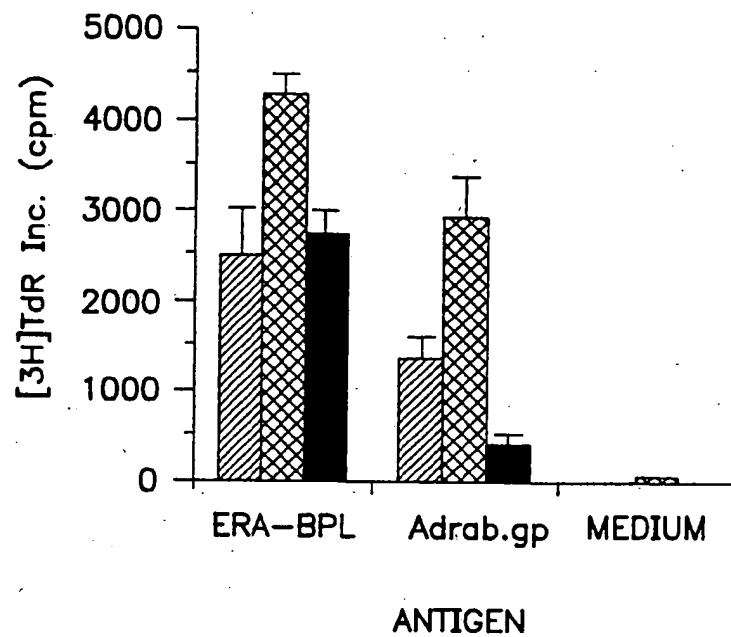


FIG. 2

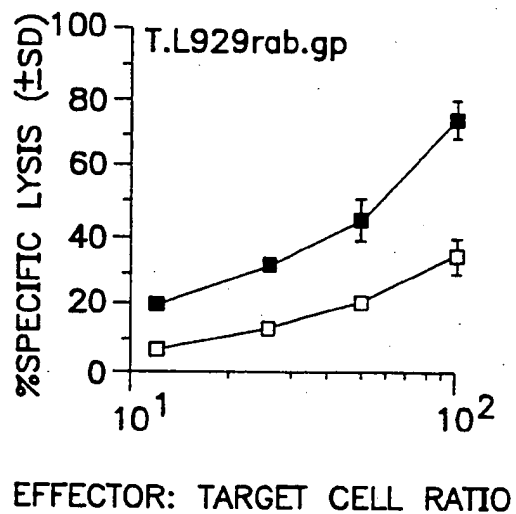


FIG. 3A

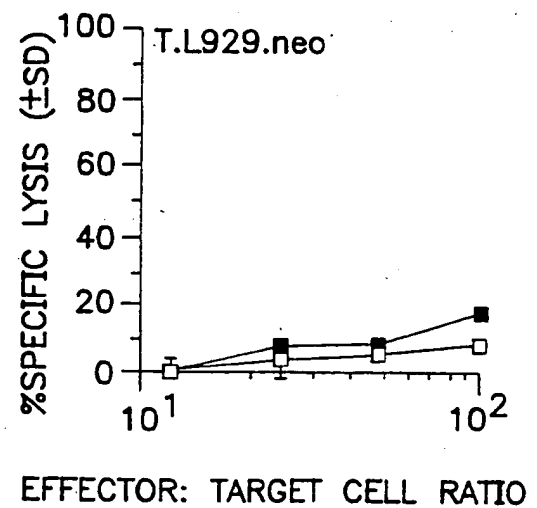


FIG. 3B

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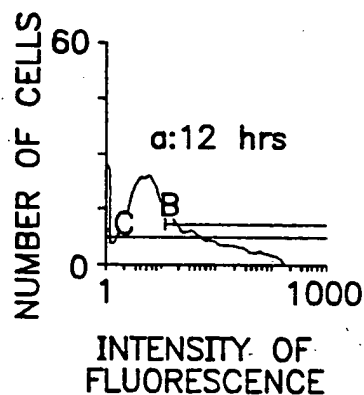


FIG. 4A

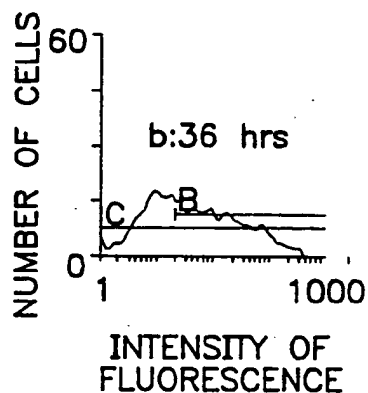


FIG. 4B

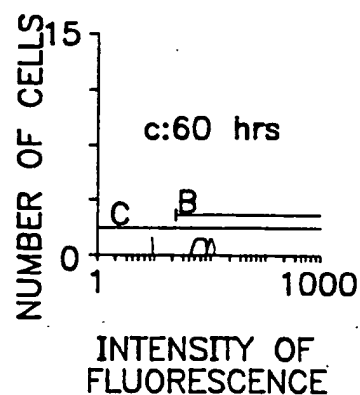


FIG. 4C

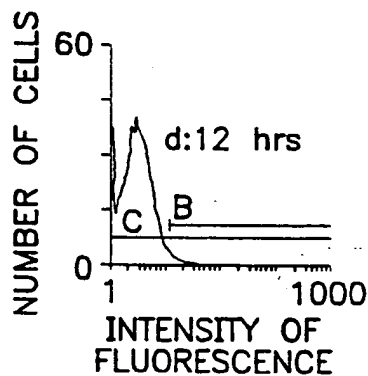


FIG. 4D

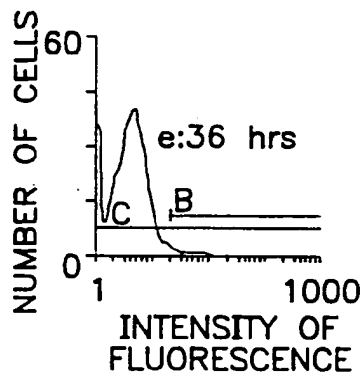


FIG. 4E

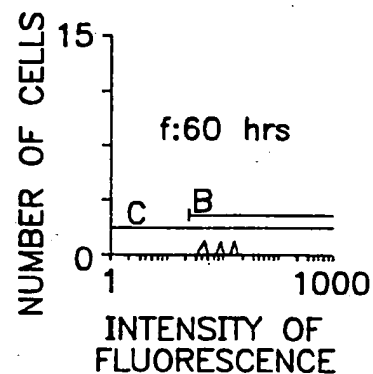


FIG. 4F

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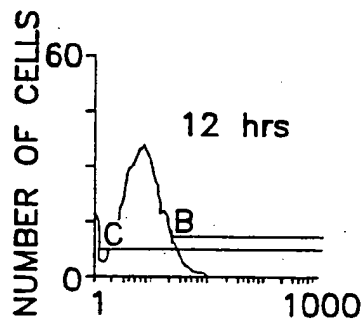
INTENSITY OF
FLUORESCENCE

FIG. 4G

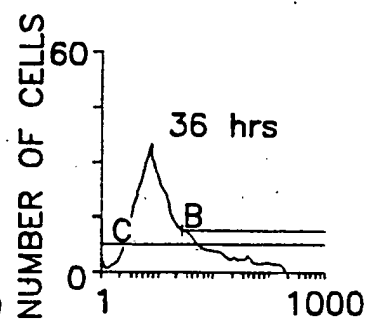
INTENSITY OF
FLUORESCENCE

FIG. 4H

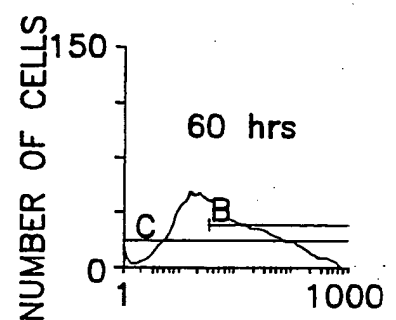
INTENSITY OF
FLUORESCENCE

FIG. 4I

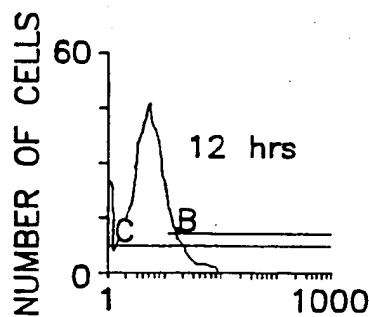
INTENSITY OF
FLUORESCENCE

FIG. 4J

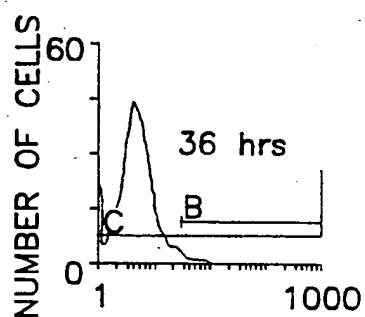
INTENSITY OF
FLUORESCENCE

FIG. 4K

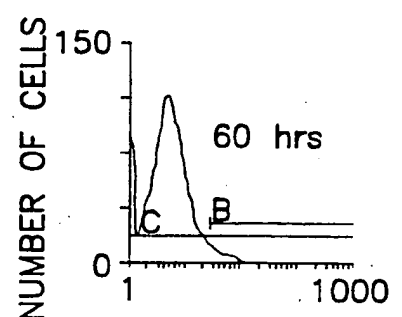
INTENSITY OF
FLUORESCENCE

FIG. 4L

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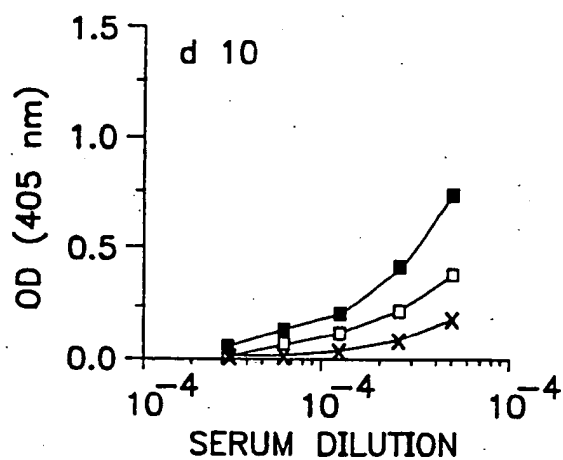


FIG. 5A

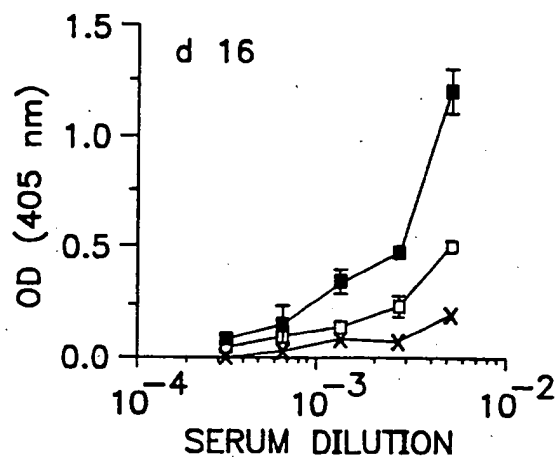


FIG. 5B

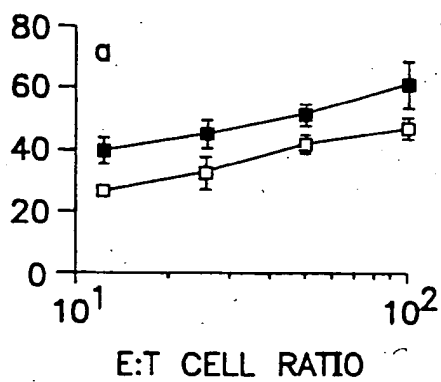


FIG. 6A

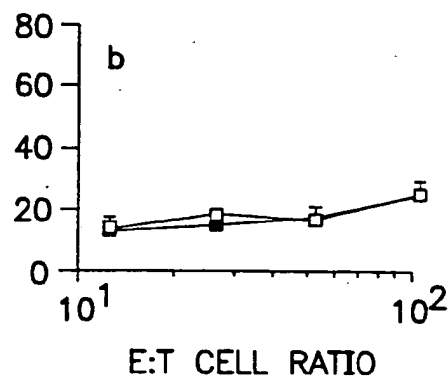


FIG. 6B

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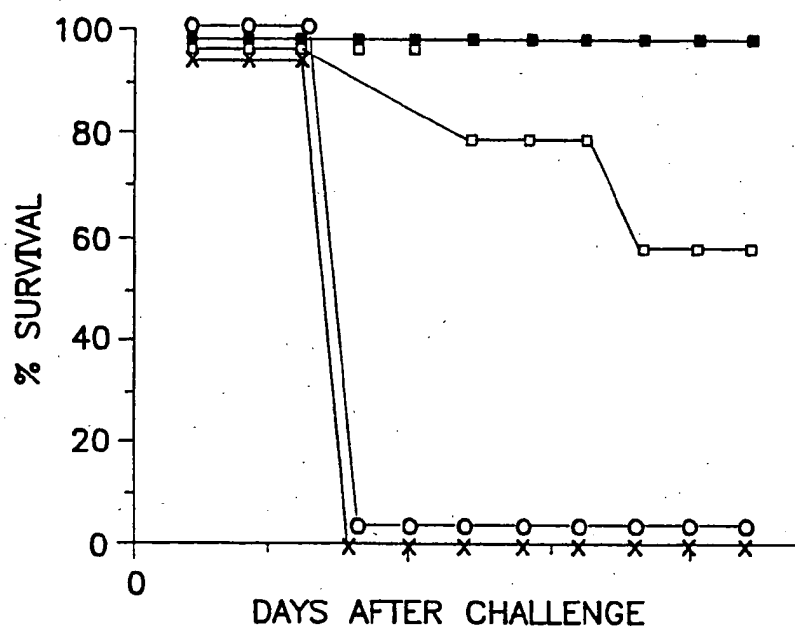


FIG. 7

SUBSTITUTE SHEET (RULE 26)

INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/09495

A. CLASSIFICATION OF SUBJECT MATTER

IPC(6) : A61K 39/12, 39/205, 39/235; C12N 7/01, 15/00, 15/09

US CL : 424/199.1, 224.1, 233.1; 935/32, 34, 57, 65; 435/235.1, 320.1

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/199.1, 224.1, 233.1; 935/32, 34, 57, 65; 435/235.1, 320.1

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

APS, CAS ONLINE, MEDLINE

search terms: Adenovirus, Vaccine, Rabies, E1, E3, Vector.

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Prevec et al. A Recombinant Human Adenovirus Vaccine against Rabies. The Journal of Infectious Diseases. January 1990, Vol. 161, pages 27-30, especially page 28 and Figure 1.	1-4, 9, 14, 15
Y	Charlton et al. Oral rabies vaccination of skunks and foxes with a recombinant human adenovirus vaccine. Archives of Virology. 1992, Vol. 123, pages 169-179, especially see pages 170 start of the third paragraph, plus table 1 and 2.	1-4, 9, 14, 15

☒ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	*T	later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
A document defining the general state of the art which is not considered to be part of particular relevance	*X*	document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
E earlier document published on or after the international filing date	*Y*	document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
L document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	*Z*	document member of the same patent family
O document referring to an oral disclosure, use, exhibition or other means		
P document published prior to the international filing date but later than the priority date claimed		

Date of the actual completion of the international search

26 AUGUST 1996

Date of mailing of the international search report

04 OCT 1996

Name and mailing address of the ISA/US
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Authorized officer

ALI SALIMI

Telephone No. (703) 308-0196

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/US96/09495

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Eloit et al. Construction of a defective adenovirus vector expressing the pseudorabies virus glycoprotein gp50 and its use as a live vaccine. Journal of General Virology. 1990, Vol. 71, pages 2425-2431, especially page 2429:Discussion.	5-8
Y	Johnson et al. Abundent Expression of Herpes Simplex Virus Glycoprotein gb Using an Adenovirus Vector. Virology. 1988, Vol. 164, pages 1-14, especially page 7.	5, 7, 8
Y	Dewar et al. Synthesis and processing of Human Immunodeficiency Virus Type 1 Envelope Proteins Encoded by a Recombinant Human Adenovirus. Journal of Virology. January 1989, Vol. 63, No. 1, pages 129-136, especially page 133.	6

Form PCT/ISA/210 (continuation of second sheet)(July 1992)*

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US96/09495

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This international report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the international application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

3. ☒ Claims Nos.: 10-13
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

- ☐ The additional search fees were accompanied by the applicant's protest.
☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet(1))(July 1992)*

